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(54) **PCRAM MEMORY CELL AND METHOD OF MAKING SAME**

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(56) **References Cited**

**U.S. PATENT DOCUMENTS**

3,271,591 A	9/1966	Ovshinsky
3,622,319 A	11/1971	Sharp
3,743,847 A	7/1973	Boland
3,961,314 A	6/1976	Klose et al.
3,966,317 A	6/1976	Wacks et al.
3,983,542 A	9/1976	Ovshinsky
3,988,720 A	10/1976	Ovshinsky
4,177,474 A	12/1979	Ovshinsky
4,267,261 A	5/1981	Hallman et al.
4,269,935 A	5/1981	Masters et al.

4,312,938 A	1/1982	Drexler et al.
4,316,946 A	2/1982	Masters et al.
4,320,191 A	3/1982	Yoshikawa et al.
4,405,710 A	9/1983	Balasubramanyam et al.
4,419,421 A	12/1983	Wichelhaus et al.
4,499,557 A	2/1985	Holmberg et al.
4,597,162 A	7/1986	Johnson et al.
4,608,296 A	8/1986	Keem et al.
4,637,895 A	1/1987	Ovshinsky et al.

(Continued)

**FOREIGN PATENT DOCUMENTS**

JP	56126916	10/1998
WO	WO 97/48032	12/1997
WO	WO 99/28914	6/1999
WO	WO 00/48196	8/2000
WO	WO 02/21542	3/2002

**OTHER PUBLICATIONS**

Helbert et al., *Intralevel hybrid resist process with submicron capability*, SPIE vol. 333 Submicron Lithography, pp. 24–29 (1982).

Kozicki, et al., “Applications of Programmable Resistance Changes in Metal-doped Chalcogenides”, Proceedings of the 1999 Symposium on Solid State Ionic Devices, Editors—E.D. Wachsman et al., The Electrochemical Society, Inc., 1–12 (1999).

(Continued)

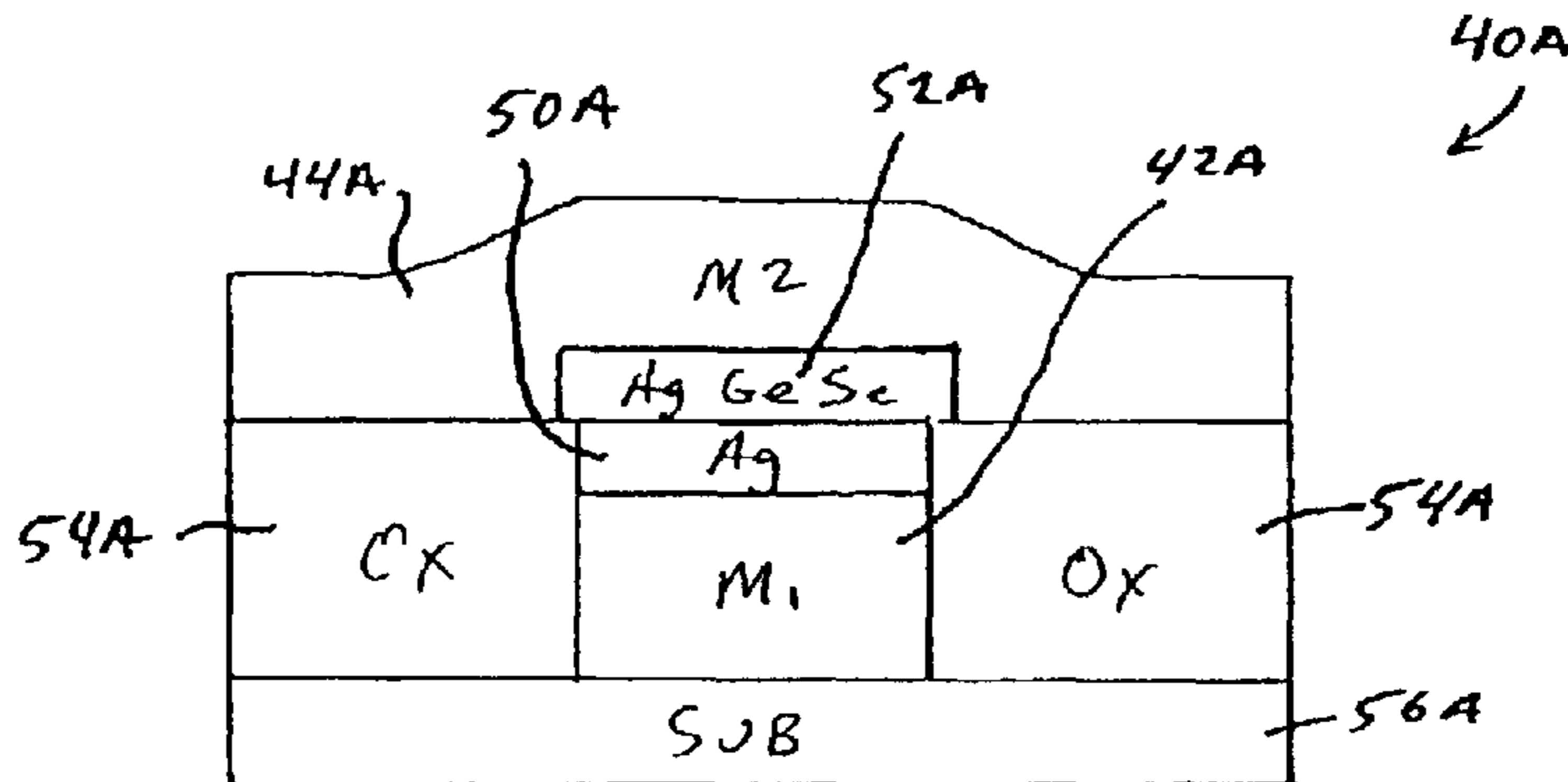
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(57) **ABSTRACT**

An inverted PCRAM cell is formed by plating the bottom electrode, made of copper for example, with a conductive material, such as silver. Chalcogenide material is disposed over the plated electrode and subjected to a conversion process so that ions from the plated material diffuse into the chalcogenide material.

**36 Claims, 8 Drawing Sheets**



U.S. PATENT DOCUMENTS

4,646,266 A	2/1987	Ovshinsky et al.	6,084,796 A	7/2000	Kozicki et al.
4,664,939 A	5/1987	Ovshinsky	6,087,674 A	7/2000	Ovshinsky et al.
4,668,968 A	5/1987	Ovshinsky et al.	6,117,720 A	9/2000	Harshfield
4,670,763 A	6/1987	Ovshinsky et al.	6,141,241 A	10/2000	Ovshinsky et al.
4,671,618 A	6/1987	Wu et al.	6,143,604 A	11/2000	Chiang et al.
4,673,957 A	6/1987	Ovshinsky et al.	6,177,338 B1	1/2001	Liaw et al.
4,678,679 A	7/1987	Ovshinsky	6,236,059 B1	5/2001	Wolstenholme et al.
4,696,758 A	9/1987	Ovshinsky et al.	RE37,259 E	7/2001	Ovshinsky
4,698,234 A	10/1987	Ovshinsky et al.	6,297,170 B1	10/2001	Gabriel et al.
4,710,899 A	12/1987	Young et al.	6,300,684 B1	10/2001	Gonzalez et al.
4,728,406 A	3/1988	Banerjee et al.	6,316,784 B1	11/2001	Zahorik et al.
4,737,379 A	4/1988	Hudgens et al.	6,329,606 B1	12/2001	Freyman et al.
4,766,471 A	8/1988	Ovshinsky et al.	6,339,544 B1	1/2002	Chiang et al.
4,769,338 A	9/1988	Ovshinsky et al.	6,348,365 B1	2/2002	Moore et al.
4,775,425 A	10/1988	Guha et al.	6,350,679 B1	2/2002	McDaniel et al.
4,768,594 A	11/1988	Ovshinsky et al.	6,376,284 B1	4/2002	Gonzalez et al.
4,795,657 A	1/1989	Formigoni et al.	6,388,324 B1	5/2002	Kozicki et al.
4,800,526 A	1/1989	Lewis	6,391,688 B1	5/2002	Gonzalez et al.
4,809,044 A	2/1989	Pryor et al.	6,404,665 B1	6/2002	Lowrey et al.
4,818,717 A	4/1989	Johnson et al.	6,414,376 B1	7/2002	Thakur et al.
4,843,443 A	6/1989	Ovshinsky et al.	6,418,049 B1	7/2002	Kozicki et al.
4,845,533 A	7/1989	Pryor et al.	6,423,628 B1	7/2002	Li et al.
4,847,674 A	7/1989	Sliwa et al.	6,429,064 B1	8/2002	Wicker
4,853,785 A	8/1989	Ovshinsky et al.	6,437,383 B1	8/2002	Xu
4,891,330 A	1/1990	Guha et al.	6,462,984 B1	10/2002	Xu et al.
5,128,099 A	7/1992	Strand et al.	6,469,364 B1	10/2002	Kozicki
5,159,661 A	10/1992	Ovshinsky et al.	6,473,332 B1	10/2002	Ignatiev et al.
5,166,756 A	11/1992	McGee et al.	6,480,438 B1	11/2002	Park
5,177,567 A	1/1993	Klersy et al.	6,487,106 B1	11/2002	Kozicki
5,219,788 A	6/1993	Abernathey et al.	6,487,113 B1	11/2002	Park et al.
5,238,862 A	8/1993	Blalock et al.	6,501,111 B1	12/2002	Lowrey
5,272,359 A	12/1993	Nagasubramanian et al.	6,507,061 B1	1/2003	Hudgens et al.
5,296,716 A	3/1994	Ovshinsky et al.	6,511,862 B1	1/2003	Hudgens et al.
5,314,772 A	5/1994	Kozicki	6,511,867 B1	1/2003	Lowrey et al.
5,315,131 A	5/1994	Kishimoto et al.	6,512,241 B1	1/2003	Lai
5,335,219 A	8/1994	Ovshinsky et al.	6,514,805 B1	2/2003	Xu et al.
5,341,328 A	8/1994	Ovshinsky et al.	6,531,373 B1	3/2003	Gill et al.
5,350,484 A	9/1994	Gardner et al.	6,534,781 B1	3/2003	Dennison
5,359,205 A	10/1994	Ovshinsky	6,545,287 B1	4/2003	Chiang
5,360,981 A	11/1994	Owen et al.	6,545,907 B1	4/2003	Lowrey et al.
5,406,509 A	4/1995	Ovshinsky et al.	6,555,860 B1	4/2003	Lowrey et al.
5,414,271 A	5/1995	Ovshinsky et al.	6,563,164 B1	5/2003	Lowrey et al.
5,500,532 A	3/1996	Kozicki et al.	6,566,700 B1	5/2003	Xu
5,512,328 A	4/1996	Yoshimura et al.	6,567,293 B1	5/2003	Lowrey et al.
5,512,773 A	4/1996	Wolf et al.	6,569,705 B1	5/2003	Chiang et al.
5,534,711 A	7/1996	Ovshinsky et al.	6,570,784 B1	5/2003	Lowrey
5,534,712 A	7/1996	Ovshinsky et al.	6,576,921 B1	6/2003	Lowrey
5,536,947 A	7/1996	Klersy et al.	6,586,761 B1	7/2003	Lowrey
5,543,737 A	8/1996	Ovshinsky	6,589,714 B1	7/2003	Maimon et al.
5,591,501 A	1/1997	Ovshinsky et al.	6,590,807 B1	7/2003	Lowrey
5,596,522 A	1/1997	Ovshinsky et al.	6,593,176 B1	7/2003	Dennison
5,687,112 A	11/1997	Ovshinsky	6,597,009 B1	7/2003	Wicker
5,694,054 A	12/1997	Ovshinsky et al.	6,605,527 B1	8/2003	Dennison et al.
5,714,768 A	2/1998	Ovshinsky et al.	6,613,604 B1	9/2003	Maimon et al.
5,726,083 A	3/1998	Takaishi	6,621,095 B1	9/2003	Chiang et al.
5,751,012 A	5/1998	Wolsteinholme et al.	6,625,054 B1	9/2003	Lowrey et al.
5,761,115 A	6/1998	Kozicki et al.	6,642,102 B1	11/2003	Xu
5,789,277 A	8/1998	Zahorik et al.	6,646,297 B1	11/2003	Dennison
5,825,046 A	10/1998	Czubatyj et al.	6,649,928 B1	11/2003	Dennison
5,841,150 A	11/1998	Gonzalez et al.	6,667,900 B1	12/2003	Lowrey et al.
5,846,889 A	12/1998	Harbison et al.	6,671,710 B1	12/2003	Ovshinsky et al.
5,896,312 A	4/1999	Kozicki et al.	6,673,648 B1	1/2004	Lowrey
5,912,839 A	6/1999	Ovshinsky et al.	6,673,700 B1	1/2004	Dennison et al.
5,914,893 A	6/1999	Kozicki et al.	6,674,115 B1	1/2004	Hudgens et al.
5,920,788 A	7/1999	Reinberg	6,687,153 B1	2/2004	Lowrey
5,933,365 A	8/1999	Klersy et al.	6,687,427 B1	2/2004	Ramalingam et al.
5,998,066 A	12/1999	Block et al.	6,690,026 B1	2/2004	Peterson
6,011,757 A	1/2000	Ovshinsky	6,696,355 B1	2/2004	Dennison
6,072,716 A	6/2000	Jacobson et al.	6,707,712 B1	3/2004	Lowrey
6,077,729 A	6/2000	Harshfield	6,714,954 B1	3/2004	Ovshinsky et al.
			2002/0000666 A1	1/2002	Kozicki et al.

2002/0072188	A1	6/2002	Gilton	
2002/0123169	A1	9/2002	Moore et al.	
2002/0123170	A1	9/2002	Moore et al.	
2002/0123248	A1	9/2002	Moore et al.	
2002/0127886	A1	9/2002	Moore et al.	
2002/0163828	A1	11/2002	Krieger et al.	
2002/0168820	A1 *	11/2002	Kozicki et al.	..... 438/268
2002/0190350	A1	12/2002	Kozicki	
2003/0001229	A1	1/2003	Moore et al.	
2003/0027416	A1	2/2003	Moore	
2003/0035314	A1	2/2003	Kozicki	
2003/0035315	A1	2/2003	Kozicki	
2003/0048744	A1	3/2003	Ovshinsky et al.	
2003/0107105	A1 *	6/2003	Kozicki	
2003/0137869	A1 *	7/2003	Kozicki	
2003/0155589	A1 *	8/2003	Campbell et al.	
2003/0155606	A1 *	8/2003	Campbell et al.	
2003/0212724	A1	11/2003	Ovshinsky et al.	
2003/0212725	A1	11/2003	Ovshinsky et al.	
2004/0035401	A1	2/2004	Ramachandran et al.	

## OTHER PUBLICATIONS

Kozicki, et al., *Nanoscale effects in devices based on chalcogenide solid solutions*, Superlattices and Microstructures, 27, 485–488 (2000).

Kozicki, et al., *Nanoscale phase separation in Ag–Ge–Se glasses*, Microelectronic Engineering, vol. 63/1–3, 155–159 (2002).

M.N. Kozicki and M. Mitkova, *Silver incorporation in thin films of selenium rich Ge–Se glasses*, Proceedings of the XIX International Congress on Glass, Society for Glass Technology, 226–227 (2001).

Abdel-All, A.; Elshafie, A.; Elhawary, M.M., DC electric-field effect in bulk and thin-film Ge<sub>5</sub>As<sub>38</sub>Te<sub>57</sub> chalcogenide glass, Vacuum 59 (2000) 845–853.

Adler, D.; Moss, S.C., Amorphous memories and bistable switches, J. Vac. Sci. Technol. 9 (1972) 1182–1189.

Adler, D.; Hensch, H.K.; Mott, S.N., The mechanism of threshold switching in amorphous alloys, Rev. Mod. Phys. 50 (1978) 209–220.

Afifi, M.A.; Labib, H.H.; El-Fazary, M.H.; Fadel, M., Electrical and thermal properties of chalcogenide glass system Se<sub>75</sub>Ge<sub>25-x</sub>Sb<sub>x</sub>, Appl. Phys. A 55 (1992) 167–169.

Afifi, M.A.; Labib, H.H.; Fouad, S.S.; El-Shazly, A.A., Electrical & thermal conductivity of the amorphous semiconductor GexSe<sub>1-x</sub>, Egypt, J. Phys. 17 (1986) 335–342.

Alekperova, Sh.M.; Gadzhieva, G.S., Current–Voltage characteristics of Ag<sub>2</sub>Se single crystal near the phase transition, Inorganic Materials 23 (1987) 137–139.

Aleksiejunas, A.; Cesnys, A., Switching phenomenon and memory effect in thin-film heterojunction of polycrystalline selenium–silver selenide, Phys. Stat. Sol. (a) 19 (1973) K169–K171.

Angell, C.A., Mobile ions in amorphous solids, Annu. Rev. Phys. Chem. 43 (1992) 693–717.

Aniya, M., Average electronegativity, medium-range-order, and ionic conductivity in superionic glasses, Solid state Ionics 136–137 (2000) 1085–1089.

Asahara, Y.; Izumitani, T., Voltage controlled switching in Cu–As–Se compositions, J. Non-Cryst. Solids 11 (1972) 97–104.

Asokan, S.; Prasad, M.V.N.; Parthasarathy, G.; Gopal, E.S.R., Mechanical and chemical thresholds in IV–VI chalcogenide glasses, Phys. Rev. Lett. 62 (1989) 808–810.

Axon Technologies Corporation, Technology Description: *Programmable Metalization Cell (PMC)*, pp. 1–6 (Pre–May 2000).

Baranovskii, S.D.; Cordes, H., On the conduction mechanism in ionic glasses, J. Chem. Phys. 111 (1999) 7546–7557.

Belin, R.; Taillades, G.; Pradel, A.; Ribes, M., Ion dynamics in superionic chalcogenide glasses: complete conductivity spectra, Solid state Ionics 136–137 (2000) 1025–1029.

Belin, R.; Zerouale, A.; Pradel, A.; Ribes, M., Ion dynamics in the argyrodite compound Ag<sub>7</sub>GeSe<sub>5</sub>I: non-Arrhenius behavior and complete conductivity spectra, Solid State Ionics 143 (2001) 445–455.

Benmore, C.J.; Salmon, P.S., Structure of fast ion conducting and semiconducting glassy chalcogenide alloys, Phys. Rev. Lett. 73 (1994) 264–267.

Bernede, J.C., Influence du metal des electrodes sur les caracteristiques courant-tension des structures M–Ag<sub>2</sub>Se–M, Thin solid films 70 (1980) L1–L4.

Bernede, J.C., Polarized memory switching in MIS thin films, Thin Solid Films 81 (1981) 155–160.

Bernede, J.C., Switching and silver movements in Ag<sub>2</sub>Se thin films, Phys. Stat. Sol. (a) 57 (1980) K101–K104.

Bernede, J.C.; Abachi, T., Differential negative resistance in metal/insulator/metal structures with an upper bilayer electrode, Thin solid films 131 (1985) L61–L64.

Bernede, J.C.; Conan, A.; Fousenan't, E.; El Bouchairi, B.; Goureaux, G., Polarized memory switching effects in Ag<sub>2</sub>Se/Se/M thin film sandwiches, Thin solid films 97 (1982) 165–171.

Bernede, J.C.; Khelil, A.; Kettaf, M.; Conan, A., Transition from S– to N–type differential negative resistance in Al–Al<sub>2</sub>O<sub>3</sub>–Ag<sub>2-x</sub>Se<sub>1+x</sub> thin film structures, Phys. Stat. Sol. (a) 74 (1982) 217–224.

Bondarev, V.N.; Pikhitsa, P.V., A dendrite model of current instability in RgAg<sub>4</sub>15, Solid State Ionics 70/71 (1994) 72–76.

Boolchand, P., The maximum in glass transition temperature (T<sub>g</sub>) near x=1/3 in GexSe<sub>1-x</sub> Glasses, Asian Journal of Physics (2000) 9, 709–72.

Boolchand, P.; Bresser, W.J., Mobile silver ions and glass formation in solid electrolytes, Nature 410 (2001) 1070–1073.

Boolchand, P.; Georgiev, D.G.; Goodman, B., Discovery of the Intermediate Phase in Chalcogenide Glasses, J. Optoelectronics and Advanced Materials, 3 (2001), 703.

Boolchand, P.; Selvanathan, D.; Wang, Y.; Georgiev, D.G.; Bresser, W.J., Onset of rigidity in steps in chalcogenide glasses, Properties and Applications of Amorphous Materials, M.F. Thorpe and Tichy, L. (eds.) Kluwer Academic Publishers, the Netherlands, 2001, pp. 97–132.

Boolchand, P.; Enzweiler, R.N.; Tenhover, M., Structural ordering of evaporated amorphous chalcogenide alloy films: role of thermal annealing, Diffusion and Defect Data vol. 53–54 (1987) 415–420.

Boolchand, P.; Grothaus, J.; Bresser, W.J.; Suranyi, P., Structural origin of broken chemical order in a GeSe<sub>2</sub> glass, Phys. Rev. B 25 (1982) 2975–2978.

Boolchand, P.; Grothaus, J.; Phillips, J.C., Broken chemical order and phase separation in GexSe<sub>1-x</sub> glasses, Solid state comm. 45 (1983) 183–185.

- Boolchand, P.; Bresser, W.J., Compositional trends in glass transition temperature ( $T_g$ ), network connectivity and nanoscale chemical phase separation in chalcogenides, Dept. of ECECS, Univ. Cincinnati (Oct. 28, 1999) 45221-0030.
- Boolchand, P.; Grothaus, J., Molecular Structure of Melt-Quenched GeSe<sub>2</sub> and GeS<sub>2</sub> glasses compared, Proc. Int. Conf. Phys. Semicond. (Eds. Chadi and Harrison) 17<sup>th</sup> (1985) 833-36.
- Bresser, W.; Boolchand, P.; Suranyi, P., Rigidity percolation and molecular clustering in network glasses, Phys. Rev. Lett. 56 (1986) 2493-2496.
- Bresser, W.J.; Boolchand, P.; Suranyi, P.; de Neufville, J.P., Intrinsically broken chalcogen chemical order in stoichiometric glasses, Journal de Physique 42 (1981) C4-193-C4-196.
- Bresser, W.J.; Boolchand, P.; Suranyi, P.; Hernandez, J.G., Molecular phase separation and cluster size in GeSe<sub>2</sub> glass, Hyperfind Interactions 27 (1986) 389-392.
- Cahen, D.; Gilet, J.-M.; Schmitz, C.; Chernyak, L.; Gartsman, K.; Jakubowicz, A., Room-Temperature, electric field induced creation of stable devices in CuInSe<sub>2</sub> Crystals, Science 258 (1992) 271-274.
- Chatterjee, R.; Asokan, S.; Titus, S.S.K., Current-controlled negative-resistance behavior and memory switching in bulk As-Te-Se glasses, J. Phys. D: Appl. Phys. 27 (1994) 2624-2672.
- Chen, C.H.; Tai, K.L., Whisker growth induced by Ag photodoping in glassy Ge<sub>x</sub>Se<sub>1-x</sub> films, Appl. Phys. Lett. 37 (1980) 1075-1077.
- Chen, G.; Cheng, J., Role of nitrogen in the crystallization of silicon nitride-doped chalcogenide glasses, J. Am. Ceram. Soc. 82 (1999) 2934-2936.
- Chen, G.; Cheng, J.; Chen, W., Effect of Si<sub>3</sub>N<sub>4</sub> on chemical durability of chalcogenide glass, J. Non-Cryst. Solids 220 (1997) 249-253.
- Cohen, M.H.; Neale, R.G.; Paskin, A., A model for an amorphous semiconductor memory device, J. Non-Cryst. Solids 8-10 (1972) 885-891.
- Croitoru, N.; Lazarescu, M.; Popescu, C.; Telnic, M.; and Vescan, L., Ohmic and non-ohmic conduction in some amorphous semiconductors, J. Non-Cryst. Solids 8-10 (1972) 781-786.
- Dalven, R.; Gill, R., Electrical properties of beta-Ag<sub>2</sub>Te and beta-Ag<sub>2</sub>Se from 4.2 to 300K, J. Appl. Phys. 38 (1967) 753-756.
- Davis, E.A., Semiconductors without form, Search 1 (1970) 152-155.
- Dearnaley, G.; Stoneham, A.M.; Morgan, D.V., Electrical phenomena in amorphous oxide films, Rep. Prog. Phys. 33 (1970) 1129-1191.
- Dejus, R.J.; Susman, S.; Volin, K.J.; Montague, D.G.; Price, D.L., Structure of Vitreous Ag-Ge-Se, J. Non-Cryst. Solids 143 (1992) 162-180.
- den Boer, W., Threshold switching in hydrogenated amorphous silicon, Appl. Phys. Lett. 40 (1982) 812-813.
- Drusedau, T.P.; Panckow, A.N.; Klabunde, F., The hydrogenated amorphous silicon/nanodisperse metal (SIMAL) system-Films of unique electronic properties, J. Non-Cryst. Solids 198-200 (1996) 829-832.
- El Bouchairi, B.; Bernede, J.C.; Burgaud, P., Properties of Ag<sub>2-x</sub>Se<sub>1+x/n</sub>-Si diodes, Thin Solid Films 110 (1983) 107-113.
- El Gharras, Z.; Bourahla, A.; Vautier, C., Role of Photoinduced defects in amorphous Ge<sub>x</sub>Se<sub>1-x</sub> photoconductivity, J. Non-Cryst. Solids 155 (1993) 171-179.
- El Ghrandi, R.; Calas, J.; Galibert, G.; Averous, M., Silver photodissolution in amorphous chalcogenide thin films, Thin Solid Films 218 (1992) 259-273.
- El Ghrandi, R.; Calas, J.; Galibert, G., Ag dissolution kinetics in amorphous GeSe<sub>5.5</sub> thin films from "in-situ" resistance measurements vs time, Phys. Stat. Sol. (a) 123 (1991) 451-460.
- El-kady, U.L., The threshold switching in semiconducting glass Ge<sub>21</sub>Se<sub>17</sub>Te<sub>62</sub>, Indian J. Phys. 70a (1996) 507-516.
- Elliott, S.R., A unified mechanism for metal photodissolution in amorphous chalcogenide materials, J. Non-Cryst. Solids 130 (1991) 85-97.
- Elliott, S.R., Photodissolution of metals in chalcogenide glasses: A Unified mechanism, J. Non-Cryst. Solids 137-138 (1991) 1031-1034.
- Elsamanoudy, M.M.; Hegab, N.A.; Fadel, M., Conduction mechanism in the pre-switching state of thin films containing Te As Ge Si, Vacuum 46 (1995) 701-707.
- El-Zahed, H.; El-Korashy, A., Influence of composition on the electrical and optical properties of Ge<sub>20</sub>BixSe<sub>80-x</sub> films, Thin Solid Films 376 (2000) 236-240.
- Fadel, M., Switching phenomenon in evaporated Se-Ge-As thin films of amorphous chalcogenide glass, Vacuum 44 (1993) 851-855.
- Fadel, M.; El-Shari, H.T., Electrical, thermal and optical properties of Se<sub>75</sub>Ge<sub>7</sub>Sb<sub>18</sub>, Vacuum 43 (1992) 253-257.
- Feng, X.; Bresser, W.J.; Boolchand, P., Directed evidence for stiffness threshold in Chalcogenide glasses, Phys. Rev. Lett. 78 (1997) 4422-4425.
- Feng, X.; Bresser, W.J.; Zhang, M.; Goodman, B.; Boolchand, P., Role of network connectivity on the elastic, plastic and thermal behavior of covalent glasses, J. Non-Cryst. Solids 222 (1997) 137-143.
- Fischer-Colbrie, A.; Bienenstock, A.; Fuoss, P.H.; Marcus, M.A., Structure and bonding in photodiffused amorphous Ag-GeSe<sub>2</sub> thin films, Phys. Rev. B 38 (1988) 12388-12403.
- Fleury, G.; Hamou, A.; Viger, C.; Vautier, C., Conductivity and crystallization of amorphous selenium, Phys. Stat. Sol. (a) 64 (1981) 311-316.
- Fritzsche, H., Optical and electrical energy gaps in amorphous semiconductors, J. Non-Cryst. Solids 6 (1971) 49-71.
- Fritzsche, H., Electronic phenomena in amorphous semiconductors, Annual Review of Materials Science 2 (1972) 697-744.
- Gates, B.; Wu, Y.; Yin, Y.; Yang, P.; Xia, Y., Single-crystalline nanowires of Ag<sub>2</sub>Se can be synthesized by templating against nanowires of trigonal Se, J. Am. Chem. Soc. (2001) currently ASAP.
- Gosain, D.P.; Nakamura, M.; Shimizu, T.; Suzuki, M.; Okano, S., Nonvolatile memory based on reversible phase transition phenomena in telluride glasses, Jap. J. Appl. Phys 28 (1989) 1013-1018.
- Guin, J.-P.; Rouxel, T.; Keryvin, V.; Sangleboeuf, J.-C.; Serre, I.; Lucas, J., Indentation creep of Ge-Se chalcogenide glasses below  $T_g$ : elastic recovery and non-Newtonian flow, J. Non Cryst. Solids 298 (2002) 260-269.
- Guin, J.-P.; Rouxel, T.; Sangleboeuf, J.-C.; Melscoet, I.; Lucas, J., Hardness, toughness and scratchability of germanium-selenium chalcogenide glasses, J. Am. Ceram. Soc. 85 (2002) 1545-52.

- Gupta, Y.P., On electrical switching and memory effects in amorphous chalcogenides, *J. Non-Cryst. Sol.* 3 (1970) 148–154.
- Haberland, D.R.; Stiegler, H., New experiments on the charge-controlled switching effect in amorphous semiconductors, *J. Non-Cryst. Solids* 8–10 (1972) 408–414.
- Haifz, M.M.; Ibrahim, M.M.; Dongol, M.; Hammad, F.H., Effect of composition on the structure and electrical properties of As–Se–Cu glasses, *J. Apply. Phys.* 54 (1983) 1950–1954.
- Hajto, J.; Rose, M.J.; Osborne, I.S.; Snell, A.J.; Le Comber, P.G.; Owen A.E. Quantization effects in metal/a–Si:H/metal devices, *Int. J. Electronics* 73 (1992) 911–913.
- Hajto, J.; Hu, J.; Snell, A.J.; Turvey, K.; Rose, M., DC and AC measurements on metal/a–Si:H/metal room temperature quantised resistance devices, *J. Non-Cryst. Solids* 266–269 (2000) 1058–1061.
- Hajto, J.; McAuley, B.; Snell, A.J.; Owen, A.E., Theory of room temperature quantized resistance effects in metal–a–Si:H–metal thin film structures, *J. Non-Cryst. Solids* 198–200 (1996) 825–828.
- Hajto, J.; Owen, A.E.; Snell, A.J.; Le Comber, P.G.; Rose, M.J., Analogue memory and ballistic electron effects in metal–amorphous silicon structures, *Phil. Mag. B* 63 (1991) 349–369.
- Hayashi, T.; Ono, Y.; Fukaya, M.; Kan, H., Polarized memory switching in amorphous Se film, *Japan. J. Appl. Phys* 13 (1974) 1163–1164.
- Hegab, N.A.; Fadel, M.; Sedeek, K., Memory switching phenomena in thin films of chalcogenide semiconductors, *Vacuum* 45 (1994) 459–462.
- Hilt, Dissertation: *Materials characterization of Silver Chalcogenide Programmable Metalization Cells*, Arizona State University, pp. Title page–114 (UMI Company, May 1999).
- Hirose et al., *High Speed Memory Behavior and Reliability of an Amorphous As<sub>2</sub>S<sub>3</sub> Film Doped Ag*, *Phys. Stat. Sol. (a)* 61, pp. 87–90 (1980).
- Hirose, Y.; Hirose, H., Polarity-dependent memory switching and behavior of Ag dendrite in Ag–photodoped amorphous As<sub>2</sub>S<sub>3</sub> films, *J. Appl. Phys.* 47 (1976) 2767–2772.
- Holmquist et al., *Reaction and Diffusion in Silver–Arsenic Chalcogenide Glass Systems*, 62 *J. Amer. Ceram. Soc.*, No. 3–4, pp. 183–188 (Mar.–Apr. 1979).
- Hong, K.S.; Speyer, R.F., Switching behavior in II–IV–V<sub>2</sub> amorphous semiconductor systems, *J. Non-Cryst. Solids* 116 (1990) 191–200.
- Hosokawa, S., Atomic and electronic structures of glassy GexSe1–x around the stiffness threshold composition, *J. Optoelectronics and Advanced Materials* 3 (2001) 199–214.
- Hu, J.; Snell, A.J.; Hajto, J.; Owen, A.E., Constant current forming in Cr/p+a–/Si:H/V thin film devices, *J. Non-Cryst. Solids* 227–230 (1998) 1187–1191.
- Hu, J.; Hajto, J.; Snell, A.J.; Owen, A.E.; Rose, M.J., Capacitance anomaly near the metal–non–metal transition in Cr–hydrogenated amorphous Si–V thin–film devices, *Phil. Mag. B.* 74 (1996) 37–50.
- Hu, J.; Snell, A.J.; Hajto, J.; Owen, A.E., Current-induced instability in Cr–p+a–Si:H–V thin film devices, *Phil. Mag. B* 80 (2000) 29–43.
- Huggett et al., *Development of silver sensitized germanium selenide photoresist by reactive sputter etching in SF<sub>6</sub>*, 42 *Appl. Phys. Lett.*, No. 7, pp. 592–594 (Apr. 1983).
- Iizima, S.; Sugi, M.; Kikuchi, M.; Tanaka, K., Electrical and thermal properties of semiconducting glasses As–Te–Ge, *Solid State Comm.* 8 (1970) 153–155.
- Ishikawa, R.; Kikuchi, M., Photovoltaic study on the photo-enhanced diffusion of Ag in amorphous films of Ge<sub>2</sub>S<sub>3</sub>, *J. Non-Cryst. Solids* 35 & 36 (1980) 1061–1066.
- Iyetomi, H.; Vashishta, P.; Kalia, R.K., Incipient phase separation in Ag/Ge/Se glasses: clustering of Ag atoms, *J. Non-Cryst. Solids* 262 (2000) 135–142.
- Jones, G.; Collins, R.A., Switching properties of thin selenium films under pulsed bias, *Thin Solid Films* 40 (1977) L15–L18.
- Joullie, A.M.; Marucchi, J., On the DC electrical conduction of amorphous As<sub>2</sub>Se<sub>7</sub> before switching, *Phys. Stat. Sol. (a)* 13 (1972) K105–K109.
- Joullie, A.M.; Marucchi, J., Electrical properties of the amorphous alloy As<sub>2</sub>Se<sub>5</sub>, *Mat. Res. Bull* 8 (1973) 433–442.
- Kaplan, T.; Adler, D., Electrothermal switching in amorphous semiconductors. *J. Non-Cryst. Solids* 8–10 (1972) 538–543.
- Kawaguchi et al., *Mechanism of photosurface deposition*, 164–166 *J. Non-Cryst. Solids*, pp. 1231–1234 (1993).
- Kawaguchi, T.; Maruno, S.; Elliott, S.R., Optical, electrical, and structural properties of amorphous Ag–Ge–S and Ag–Ge–Se films and comparison of photoinduced and thermally induced phenomena of both systems, *J. Appl. Phys.* 79 (1996) 9096–9104.
- Kawaguchi, T.; Masui, K., Analysis of change in optical transmission spectra resulting from Ag photodoping in chalcogenide film, *Japn. J. Appl. Phys.* 26 (1987) 15–21.
- Kawasaki, M.; Kawamura, J.; Nakamura, Y.; Aniya, M., Ionic conductivity of Ag<sub>x</sub>(GeSe<sub>3</sub>)<sub>1–x</sub> (0 ≤ x ≤ 0.571) glasses, *Solid state Ionics* 123 (1999) 259–269.
- Kluge, G.; Thomas, A.; Klages, R.; Grotzschel, R., Silver photodiffusion in amorphous GexSe<sub>100–x</sub>, *J. Non-Cryst. Solids* 124 (1990) 186–193.
- Kolobov, A.V., On the origin of p–type conductivity in amorphous chalcogenides, *J. Non-Cryst. Solids* 198–200 (1996) 728–731.
- Kolobov, A.V., Lateral diffusion of silver in vitreous chalcogenide films, *J. Non-Cryst. Solids* 137–138 (1991) 1027–1030.
- Korkinova, Ts.N.; Andreichin, R.E., Chalcogenide glass polarization and the type of contacts, *J. Non-Cryst. Solids* 194 (1996) 256–259.
- Kotkata, M.F.; Afif, M.A.; Labib, H.H.; Hegab, N.A.; Abdel-Aziz, M.M., Memory switching in amorphous GeSeTe chalcogenide semiconductor films, *Thin Solid Films* 240 (1994) 143–146.
- Lakshminarayan, K.N.; Srivastava, K.K.; Panwar, O.S.; Dumar, A., Amorphous semiconductor devices: memory and switching mechanism, *J. Instn Electronics & Telecom. Engrs* 27 (1981) 16–19.
- Lal, M.; Goyal N., Chemical bond approach to study the memory and threshold switching chalcogenide glasses, *Indian Journal of pure & appl. phys.* 29 (1991) 303–304.
- Leimer, F.; Stotzel, H.; Kottwitz, A., Isothermal electrical polarisation of amorphous GeSe films with blocking Al contacts influenced by Poole–Frenkel conduction, *Phys. Stat. Sol. (a)* 29 (1975) K129–K132.
- Leung, W.; Cheung, N.; Neureuther, A.R., Photoinduced diffusion of Ag in GexSe<sub>1–x</sub> glass, *Appl. Phys. Lett.*, 46 (1985) 543–545.

- Matsushita, T.; Yamagami, T.; Okuda, M., Polarized memory effect observed on Se-SnO<sub>2</sub> system, *Jap. J. Appl. Phys.* 11 (1972) 1657-1662.
- Matsushita, T.; Yamagami, T.; Okuda, M., Polarized memory effect observed on amorphous selenium thin films *Jpn. J. Appl. Phys.* 11 (1972) 606.
- Mazurier, F.; Levy, M.; Souquet, J.L., Reversible and irreversible electrical switching in TeO<sub>2</sub>-V<sub>2</sub>O<sub>5</sub> based glasses, *Journal de Physique IV* 2 (1992) C2-185-C2-188.
- McHardy et al., *The dissolution of metals in amorphous chalcogenides and the effects of electron and ultraviolet radiation*, 20 *J. Phys. C.: Solid State Phys.*, pp. 4055-4075 (1987)f.
- Messoussi, R.; Bernede, J.C.; Benhida, S.; Abachi, T.; Latef, A., Electrical characterization of M/Se structures (M=Ni, Bi), *Mat. Chem. And Phys* 28 (1991) 253-258.
- Mitkova, M.; Boolchand, P., Microscopic origin of the glass forming tendency in chalcogenides and constraint theory, *J. Non-Cryst. Solids* 240 (1998) 1-21.
- Mitkova, M.; Kozicki, M.N., Silver incorporation in Ge-Se glasses used in programmable metallization cell devices, *J. Non-Cryst. Solids* 299-302 (2002) 1023-1027.
- Mitkova, M.; Wang, Y.; Boolchand, P., Dual chemical role of Ag as an additive in chalcogenide glasses, *Phys. Rev. Lett.* 83 (1999) 3848-3851.
- Miyatani, S.-y., Electronic and ionic conduction in (Ag<sub>x</sub>Cu<sub>1-x</sub>)<sub>2</sub>Se, *J. Phys. Soc. Japan* 34 (1973) 423-432.
- Miyatani, S.-y., Electrical properties of Ag<sub>2</sub>Se, *J. Phys. Soc. Japan* 13 (1958) 317.
- Miyatani, S.-y., Ionic conduction in beta-Ag<sub>2</sub>Te and beta-Ag<sub>2</sub>Se, *Journal Phys. Soc. Japan* 14 (1959) 996-1002.
- Mott, N.F., Conduction in glasses containing transition metal ions, *J. Non-Cryst. Solids* 1 (1968) 1-17.
- Nakayama, K.; Kitagawa, T.; Ohmura, M.; Suzuki, M., Nonvolatile memory based on phase transitions in chalcogenide thin films, *Jpn. J. Appl. Phys* 32 (1993) 564-569.
- Nakayama, K.; Kojima, K.; Hayakawa, F.; Imai, Y.; Kitagawa, A.; Suzuki, M., Submicron nonvolatile memory cell based on reversible phase transition in chalcogenide glasses, *Jpn. J. Appl. Phys.* 39 (2000) 6157-6161.
- Nang, T.T.; Okuda, M.; Matsushita, T.; Yokota, S.; Suzuki, A., Electrical and optical parameters of GexSe<sub>1-x</sub> amorphous thin films, *Jap. J. App. Phys* 15 (1976) 849-853.
- Narayanan, R.A.; Asokan, S.; Kumar, A., Evidence concerning the effect of topology on electrical switching in chalcogenide network glasses, *Phys. Rev. B* 54 (1996) 4413-4415.
- Neale, R.G.; Aseltine, J.A., The application of amorphous materials to computer memories, *IEEE transactions on electron dev.* Ed-20 (1973) 195-209.
- Ovshinsky S.R.; Fritzsche, H., Reversible structural transformations in amorphous semiconductors for memory and logic, *Mettalurgical transactions* 2 (1971) 641-645.
- Ovshinsky, S.R., Reversible electrical switching phenomena in disordered structures, *Phys. Rev. Lett.* 21 (1968) 1450-1453.
- Owen, A.E.; LeComber, P.G.; Sarrabayrouse, G.; Spear, W.E., New amorphous-silicon electrically programmable nonvolatile switching device, *IEE Proc.* 129 (1982) 51-54.
- Owen, A.E.; Firth, A.P.; Ewen, P.J.S., Photo-induced structural and physico-chemical changes in amorphous chalcogenide semiconductors, *Phil. Mag. B* 52 (1985) 347-362.
- Owen, A.E.; LeComber, P.G.; Hajto, J.; Rose, M.J.; Snell, A.J., Switching in amorphous devices, *Int. J. Electronics* 73 (1992) 897-906.
- Owen et al., *Metal-Chalcogenide Photoresists for High Resolution Lithography and Sub-Micron Structures*, *Nanostructure Physics and Fabrication*, pp. 447-451 (M. Reed ed. 1989).
- Pearson, A.D.; Miller, C.E., Filamentary conduction in semi-conducting glass diodes, *App. Phys. Lett.* 14 (1969) 280-282.
- Pinto, R.; Ramanathan, K.V., Electric field induced memory switching in thin films of the chalcogenide system Ge-As-Se, *Appl. Phys. Lett.* 19 (1971) 221-223.
- Popescu, C., The effect of local non-uniformities on thermal switching and high field behavior of structures with chalcogenide glasses, *Solid-state electronics* 18 (1975) 671-681.
- Popescu, C.; Croitoru, N., The contribution of the lateral thermal instability to the switching phenomenon, *J. Non-Cryst. Solids* 8-10 (1972) 531-537.
- Popov, A.I.; Geller, I.KH.; Shemetova, V.K., Memory and threshold switching effects in amorphous selenium, *Phys. Stat. Sol. (a)* 44 (1977) K71-K73.
- Prakash, S.; Asokan, S.; Ghare, D.B., Easily reversible memory switching in Ge-As-Te glasses, *J. Phys. D: Appl. Phys* 29 (1996) 2004-2008.
- Rahman, S.; Silvarama Sastry, G., Electronic switching in Ge-Bi-Se-Te glasses, *Mat. Sci. and Eng. B12* (1992) 219-222.
- Ramesh, K.; Asokan, S.; Sangunni, K.S.; Gopal, E.S.R., Electrical Switching in germanium telluride glasses doped with Cu and Ag, *Appl. Phys. A* 69 (1999) 421-425.
- Rose, M.J.; Hajto, J.; Lecomber, P.G.; Gage, S.M.; Choi, W.K.; Snell, A.J.; Owen, A.E., Amorphous silicon analogue memory devices, *J. Non-Cryst. Solids* 115 (1989) 168-170.
- Rose, M.J.; Snell, A.J.; Lecomber, P.G.; Hajto, J.; Fitzgerald, A.G.; Owen, A.E., Aspects of non-volatility in a-Si:H Memory devices, *Mat. Res. Soc. Symp. Proc. V* 258, 1992, 1075-1080.
- Schuocker, D.; Rieder, G., On the reliability of amorphous chalcogenide switching devices, *J. Non-Cryst. Solids* 29 (1978) 397-407.
- Sharma, A.K.; Singh, B., Electrical conductivity measurements of evaporated selenium films in vacuum, *Proc. Indian Natn. Sci. Acad.* 46, A, (1980) 362-368.
- Sharma, P., Structural, electrical and optical properties of silver selenide films, *Ind. J. Of pure and applied phys.* 35 (1997) 424-427.
- Shimizu et al., *The Photo-Erasable Memory Switching Effect of Ag Photo-Doped Chalcogenide Glasses*, 46 *B. Chem Soc. Japan*, No. 12, pp. 3662-3365 (1973).
- Snell, A.J.; Lecomber, P.G.; Hajto, J.; Rose, M.J.; Owen, A.E.; Osborne, I.L., Analogue memory effects in metal/a-Si:H/metal memory devices, *J. Non-Cryst. Solids* 137-138 (1991) 1257-1262.
- Snell, A.J.; Hajto, J.; Rose, M.J.; Osborne, L.S.; Holmes, A.; Owen, A.E.; Gibson, R.A.G., Analogue memory effects in metal/a-Si:H/metal thin film structures, *Mat. Res. Soc. Symp. Proc. V* 297, 1993, 1017-1021.
- Steventon, A.G., Microfilaments in amorphous chalcogenide memory devices, *J. Phys. D: Appl. Phys* 8 (1975) L120-L122.
- Steventon, A.G., The switching mechanism in amorphous chalcogenide memory devices, *J. Non-Cryst. Solids* 21 (1976) 319-329.

- Stocker, H.J., Bulk and thin film switching and memory effects in semiconducting chalcogenide glasses, *App. Phys. Lett.* 15 (1969) 55–57.
- Tanaka, K., Ionic and mixed conductions in Ag photodoping process, *Mod. Phys. Lett B* 4 (1990) 1373–1377.
- Tanaka, K.; Iizima, S.; Sugi, M.; Okada, Y.; Kikuchi, M., Thermal effects on switching phenomenon in chalcogenide amorphous semiconductors, *Solid State Comm.* 8 (1970) 387–389.
- Thornburg, D.D., Memory switching in a Type I amorphous chalcogenide, *J. Elect. Mat.* 2 (1973) 3–15.
- Thornburg, D.D., Memory switching in amorphous arsenic triselenide, *J. Non-Cryst. Solids* 11 (1972) 113–120.
- Thornburg, D.D.; White, R.M., Electric field enhanced phase separation and memory switching in amorphous arsenic triselenide, *Journal(??)* (1972) 4609–4612.
- Tichy, L.; Ticha, H., Remark on the glass-forming ability in  $GexSe_{1-x}$  and  $AsxSe_{1-x}$  systems, *J. Non-Cryst. Solids* 261 (2000) 277–281.
- Titus, S.S.K.; Chatterjee, R.; Asokan, S., Electrical switching and short-range order in As–Te glasses, *Phys. Rev. B* 48 (1993) 14650–14652.
- Tranchant, S.; Peytavin, S.; Ribes, M.; Flank, A.M.; Dexpert, H.; Lagarde, J.P., Silver chalcogenide glasses Ag–Ge–Se: Ionic conduction and exafs structural investigation, *Transport-structure relations in fast ion and mixed conductors Proceedings of the 6th Riso International symposium*, Sep. 9–13, 1985.
- Tregouet, Y.; Bernede, J.C., Silver movements in  $Ag_2Te$  thin films: switching and memory effects, *Thin Solid Films* 57 (1979) 49–54.
- Uemura, O.; Kameda, Y.; Kokai, S.; Satow, T., Thermally induced crystallization of amorphous  $Ge_{0.4}Se_{0.6}$ , *J. Non-Cryst. Solids* 117–118 (1990) 219–221.
- Uttecht, R.; Stevenson, H.; Sie, C.H.; Griener, J.D.; Raghavan, K.S., Electric field induced filament formation in As–Te–Ge glass, *J. Non-Cryst. Solids* 2 (1970) 358–370.
- Viger, C.; Lefrancois, G.; Fleury, G., Anomalous behaviour of amorphous selenium films, *J. Non-Cryst. Solids* 33 (1976) 267–272.
- Vodenicharov, C.; Parvanov, S.; Petkov, P., Electrode-limited currents in the thin-film M–GeSe–M system, *Mat. Chem. And Phys.* 21 (1989) 447–454.
- Wang, S.-J.; Misium, G.R.; Camp, J.C.; Chen, K.-L.; Tigelaar, H.L., High performance Metal/silicide antifuse, *IEEE electron dev. Lett.* 13 (1992) 471–472.
- Weirauch, D.F., Threshold switching and thermal filaments in amorphous semiconductors, *App. Phys. Lett.* 16 (1970) 72–73.
- West, W.C.; Sieradzki, K.; Kardynal, B.; Kozicki, M.N., Equivalent circuit modeling of the  $Ag|As_{0.24}S_{0.36}Ag_{0.40}|Ag$  System prepared by photodissolution of Ag, *J. Electrochem. Soc.* 145 (1998) 2971–2974.
- West, W.C., Electrically erasable non-volatile memory via electrochemical deposition of multifractal aggregates, Ph.D. Dissertation, ASU 1998.
- Zhang, M.; Mancini, S.; Bresser, W.; Boolchang, P., Variation of glass transition temperature,  $T_g$ , with average coordination number,  $\langle m \rangle$ , in network glasses: evidence of a threshold behavior in the slope  $|dT_g/d\langle m \rangle|$  at the rigidity percolation threshold ( $\langle m \rangle = 2.4$ ), *J. Non-Cryst. Solids* 151 (1992) 149–154.
- Jacques Coderre; *Electroless Ni/Au and Process Control; Process Control; Printed Circuit Fabrication 1978–1998; pgs. 42–46.*
- Don Cullen; *Electroless Nickel/Immersion Gold; Ni/Au; Printed Circuit Fabrication 1978–1998; pgs. 32–39.*
- Jean W. Chevaier; *Electroless Gold Plating; pgs. 323–325.*

\* cited by examiner

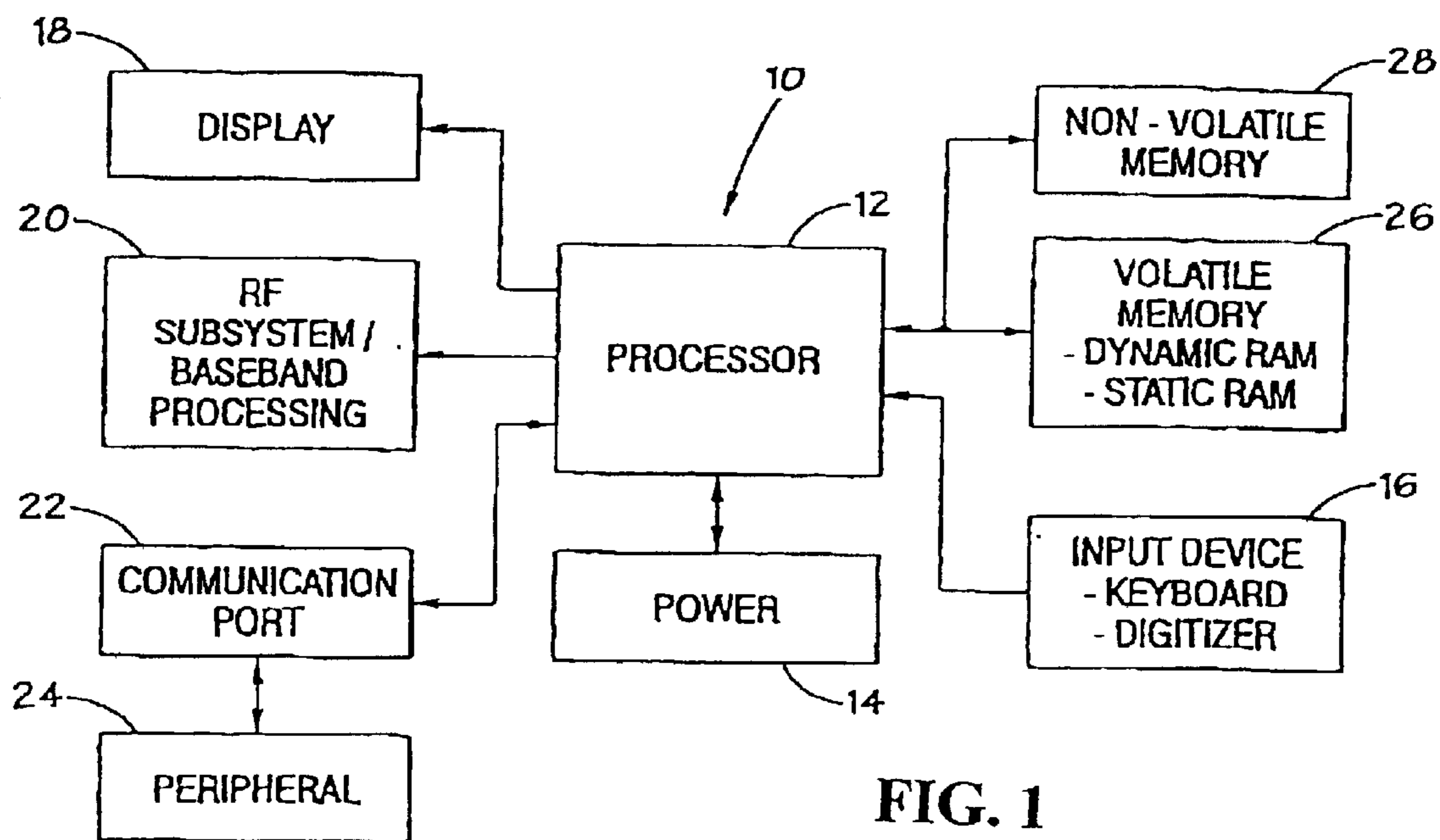


FIG. 1



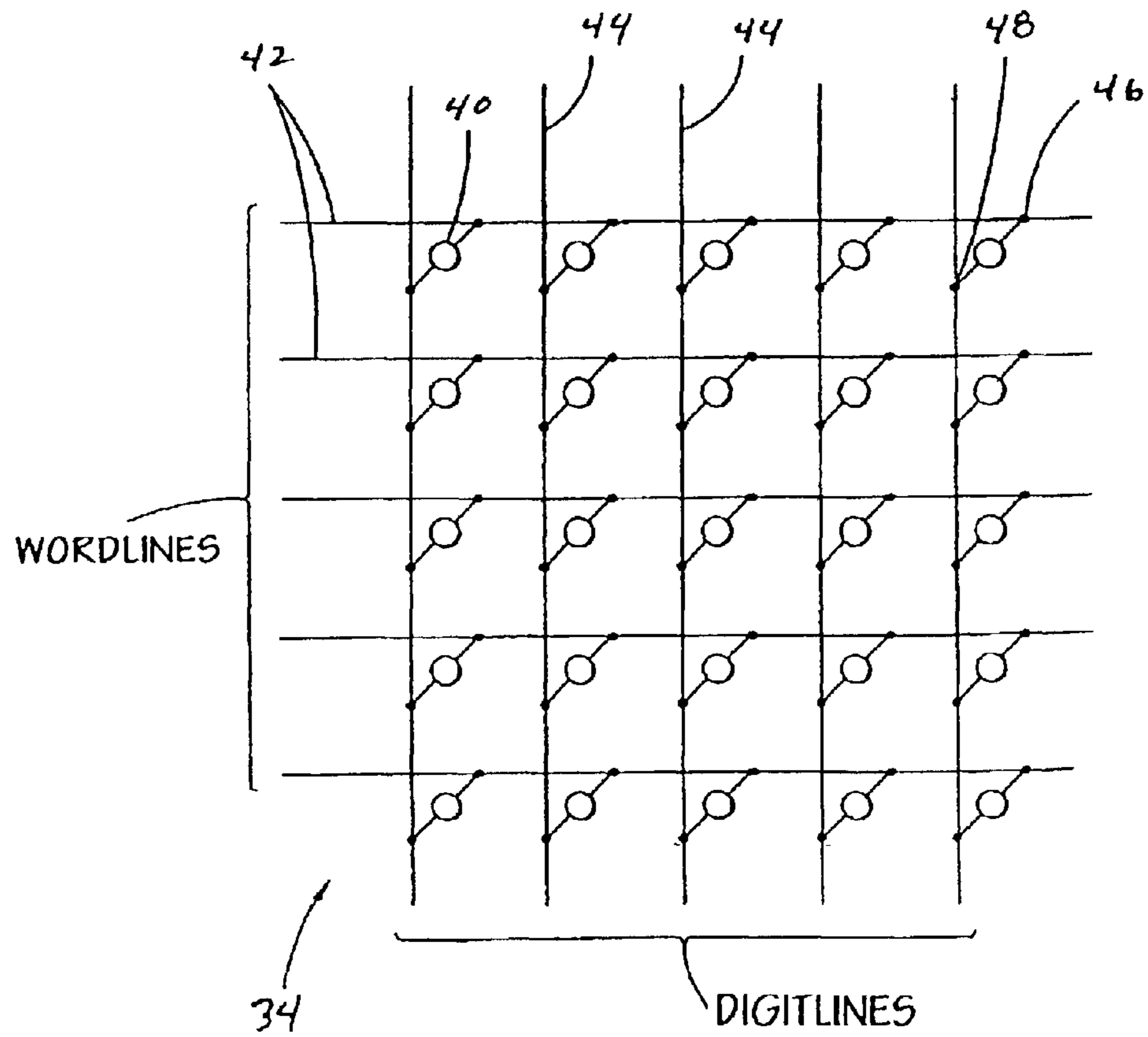
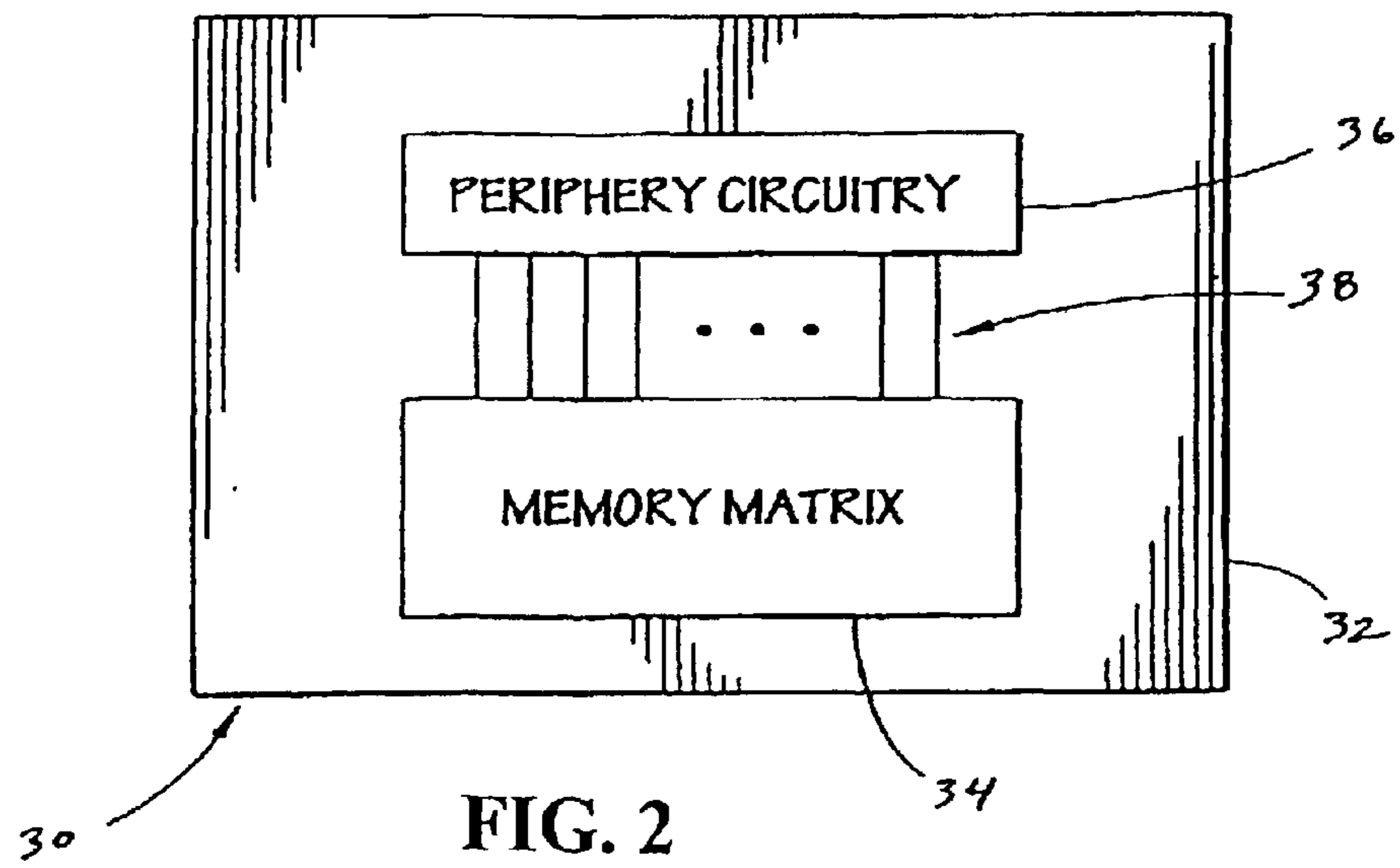


FIG. 3

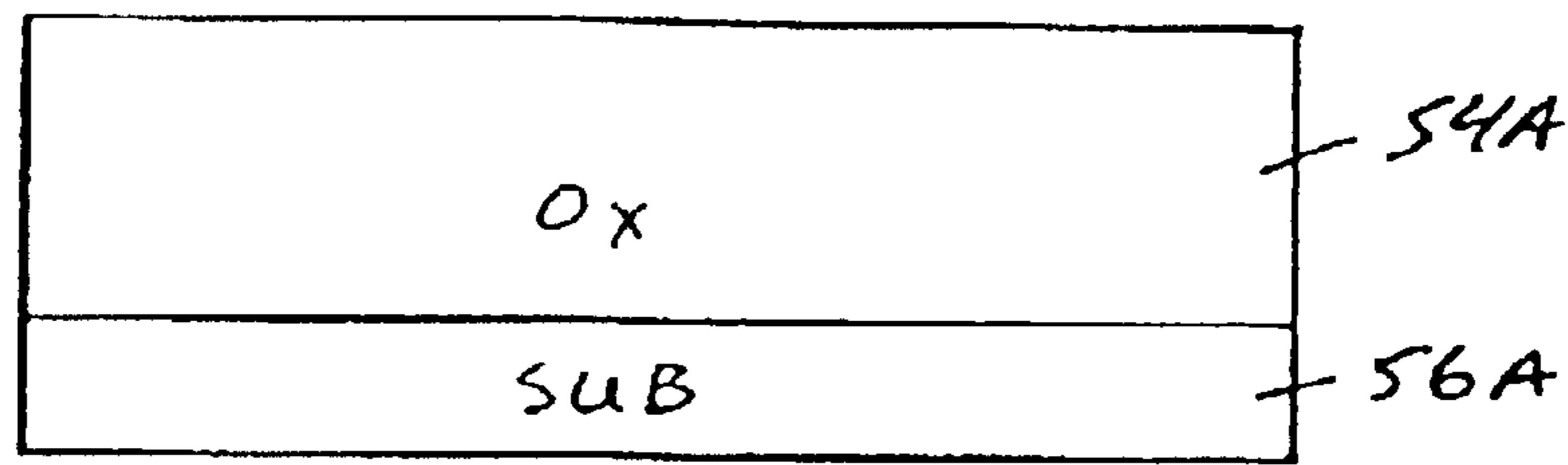


FIG. 4

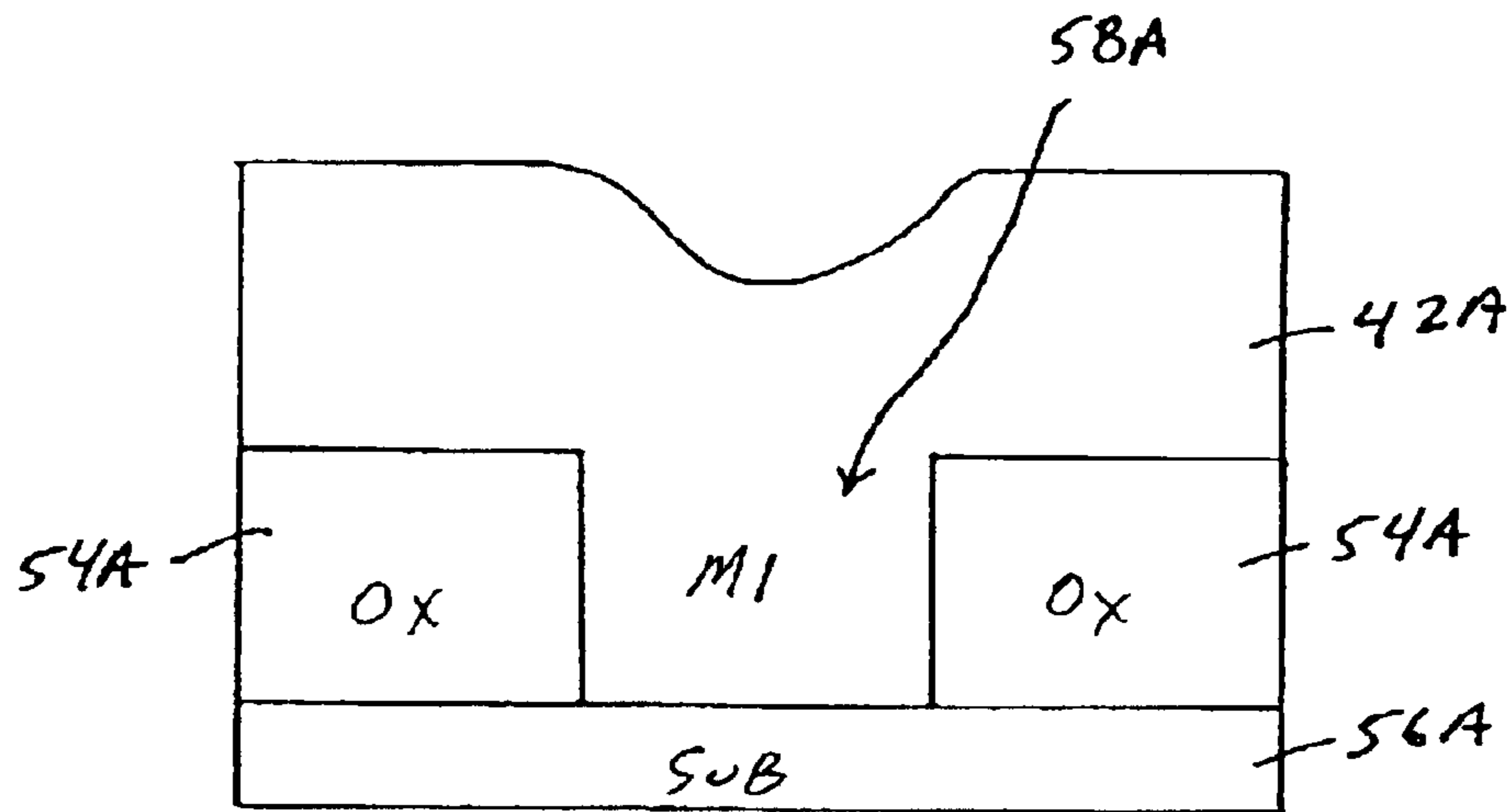


FIG. 5

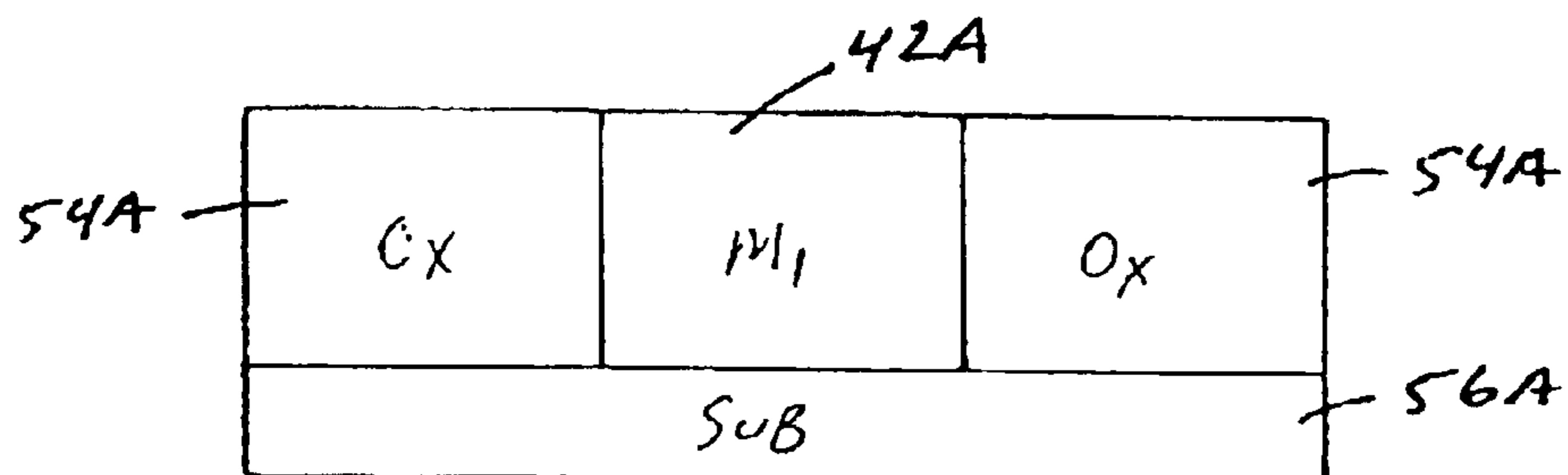


FIG. 6

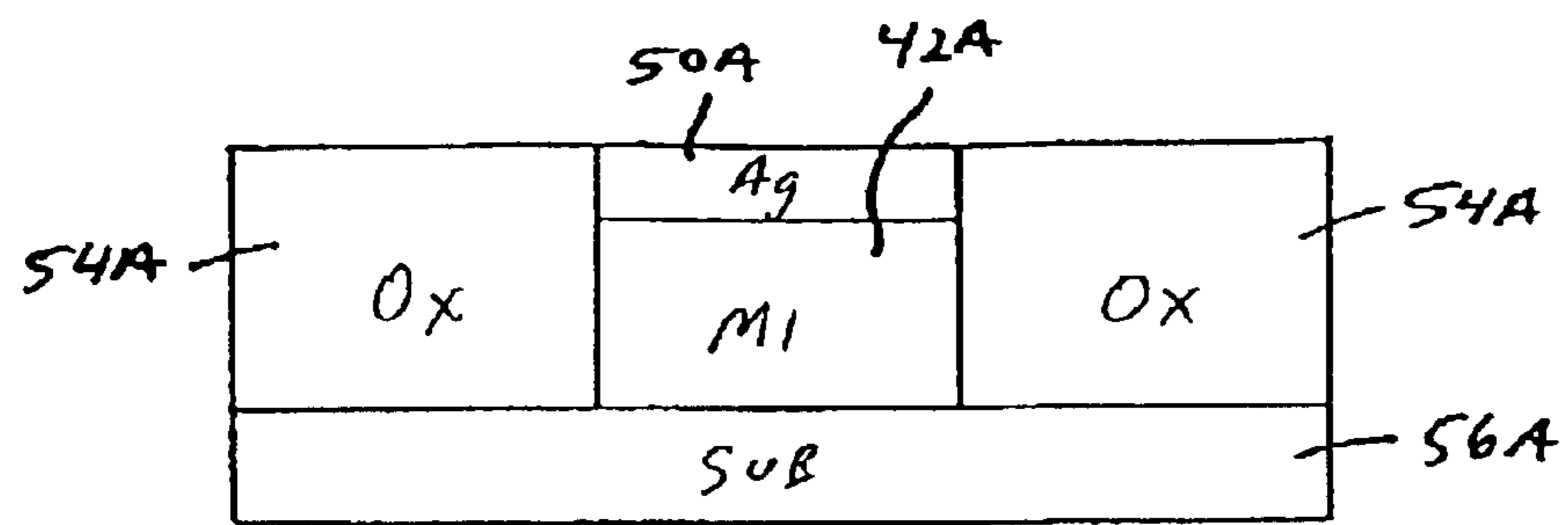


FIG. 7

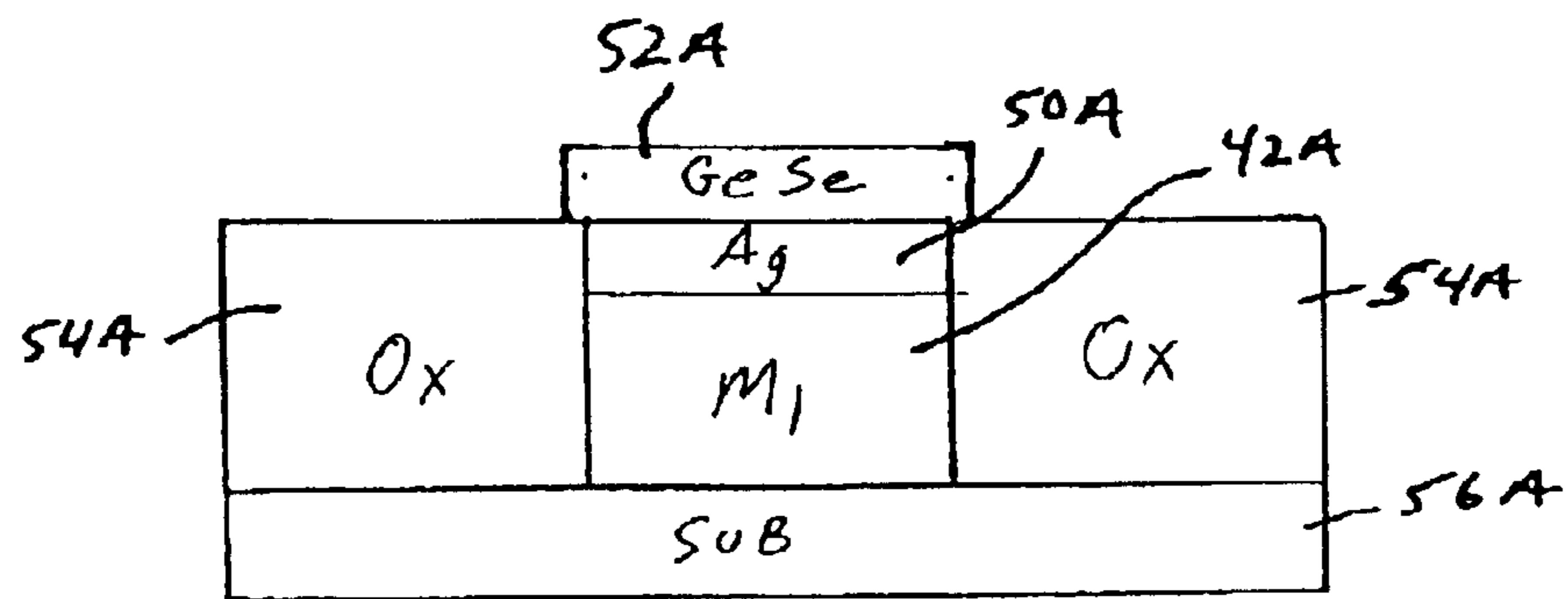


FIG. 8

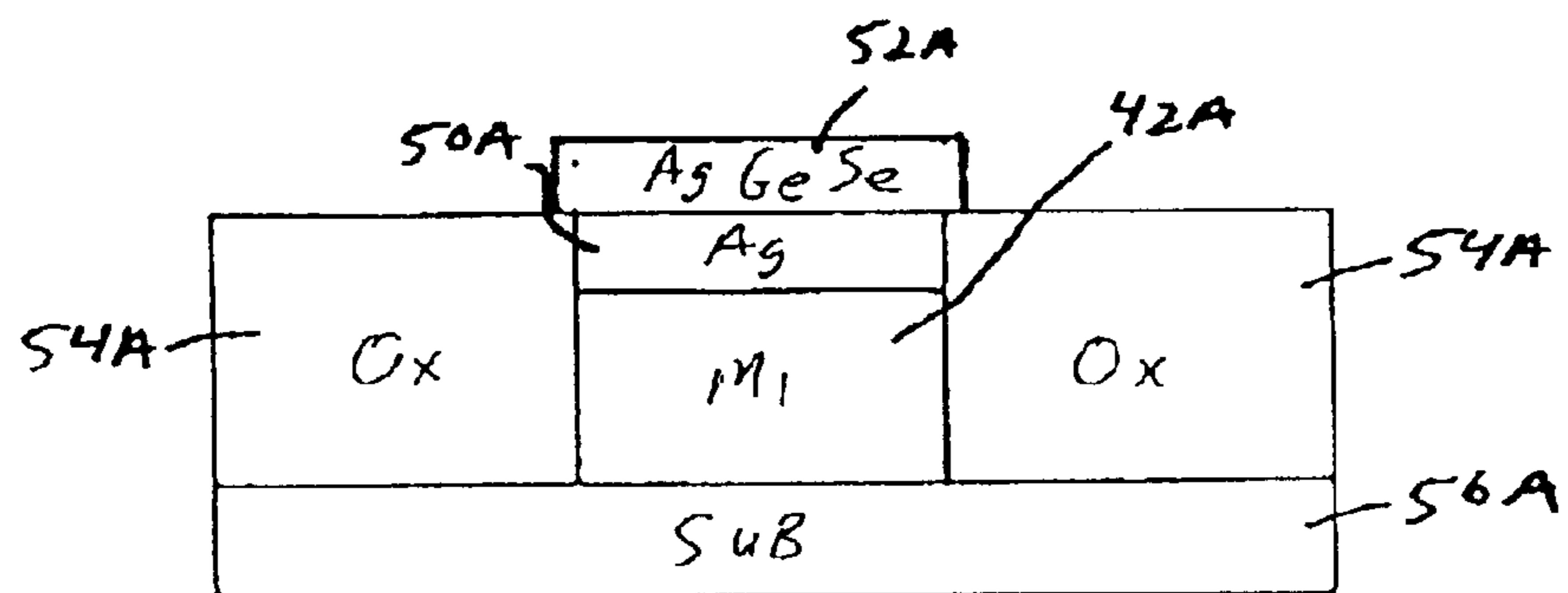


FIG. 9

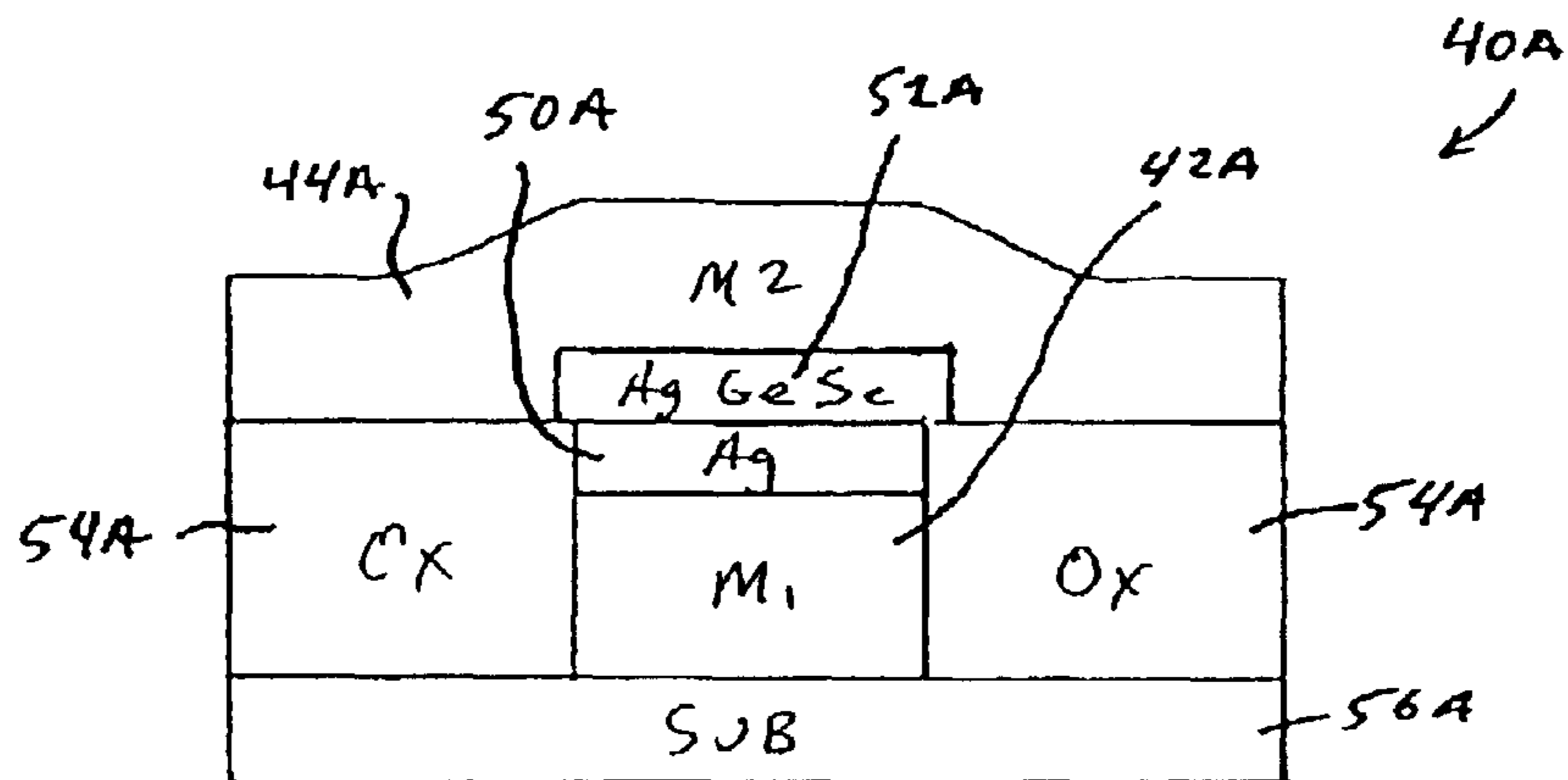


FIG. 10

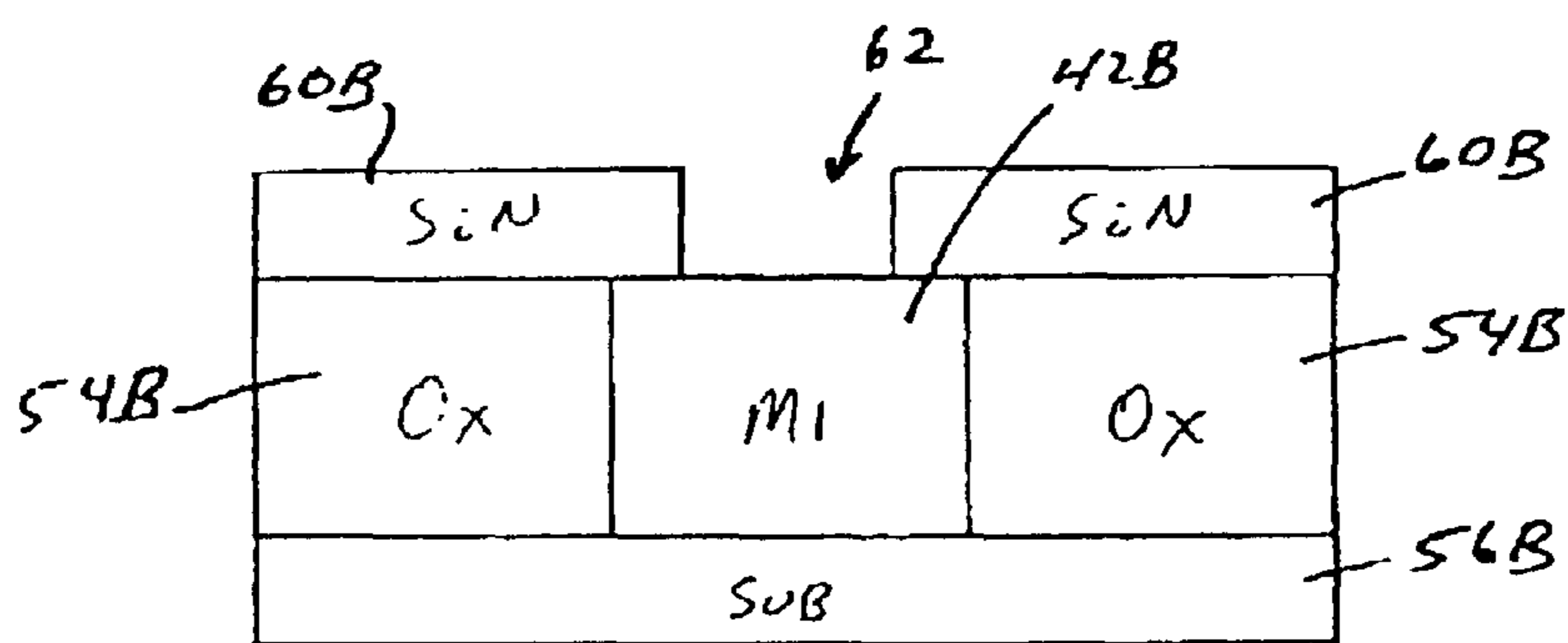


FIG. 11

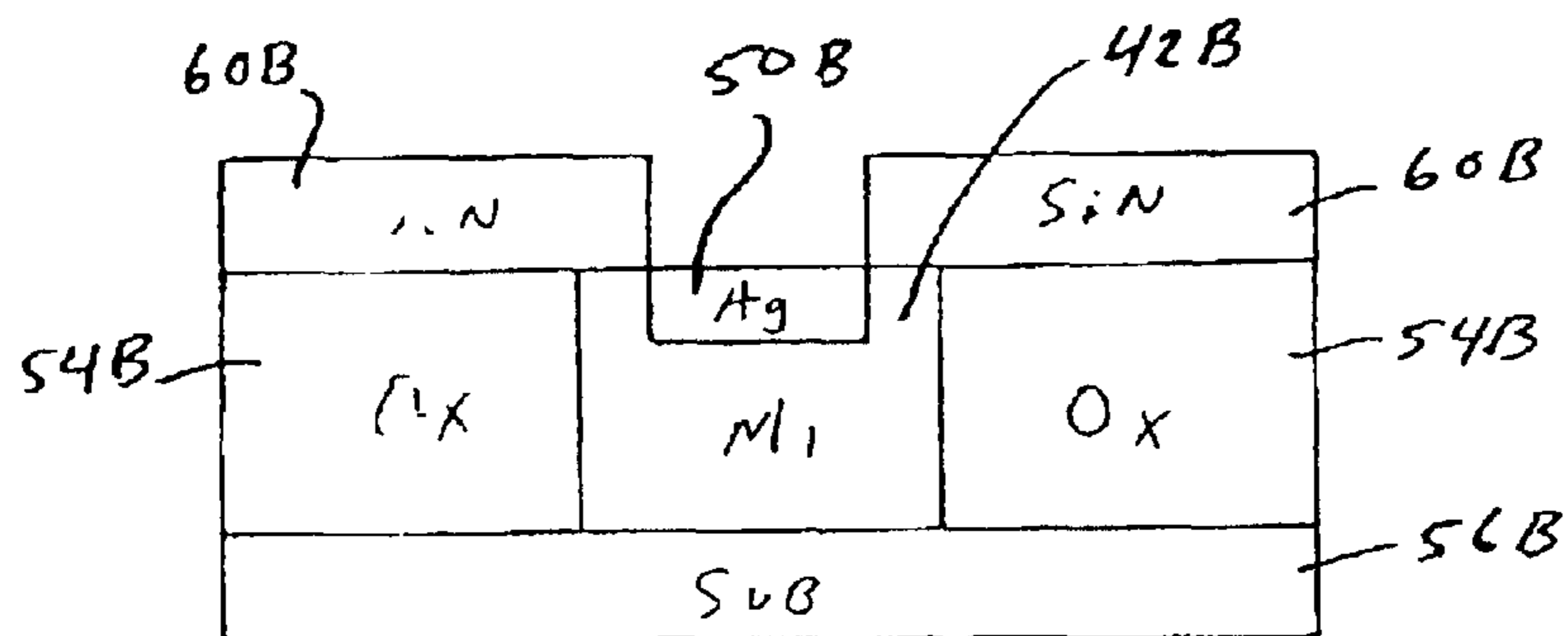


FIG. 12

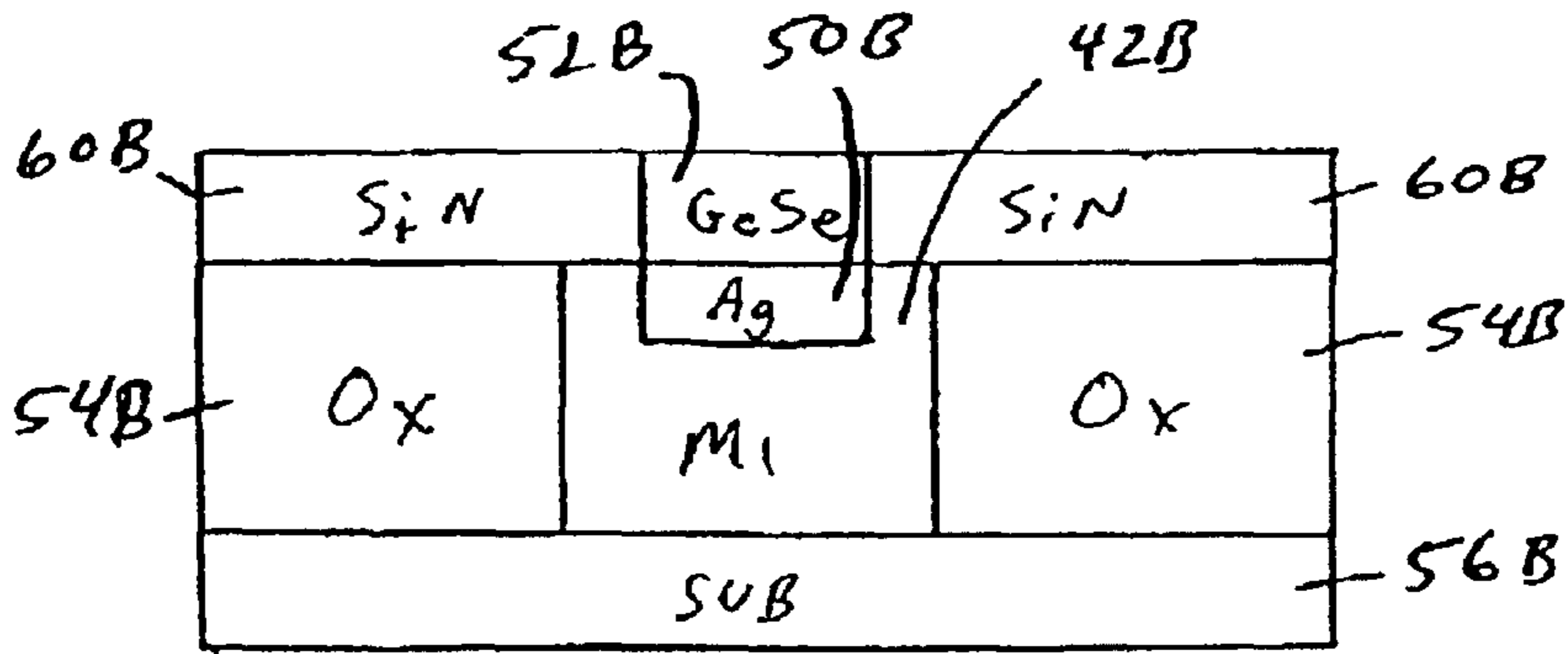


FIG. 13

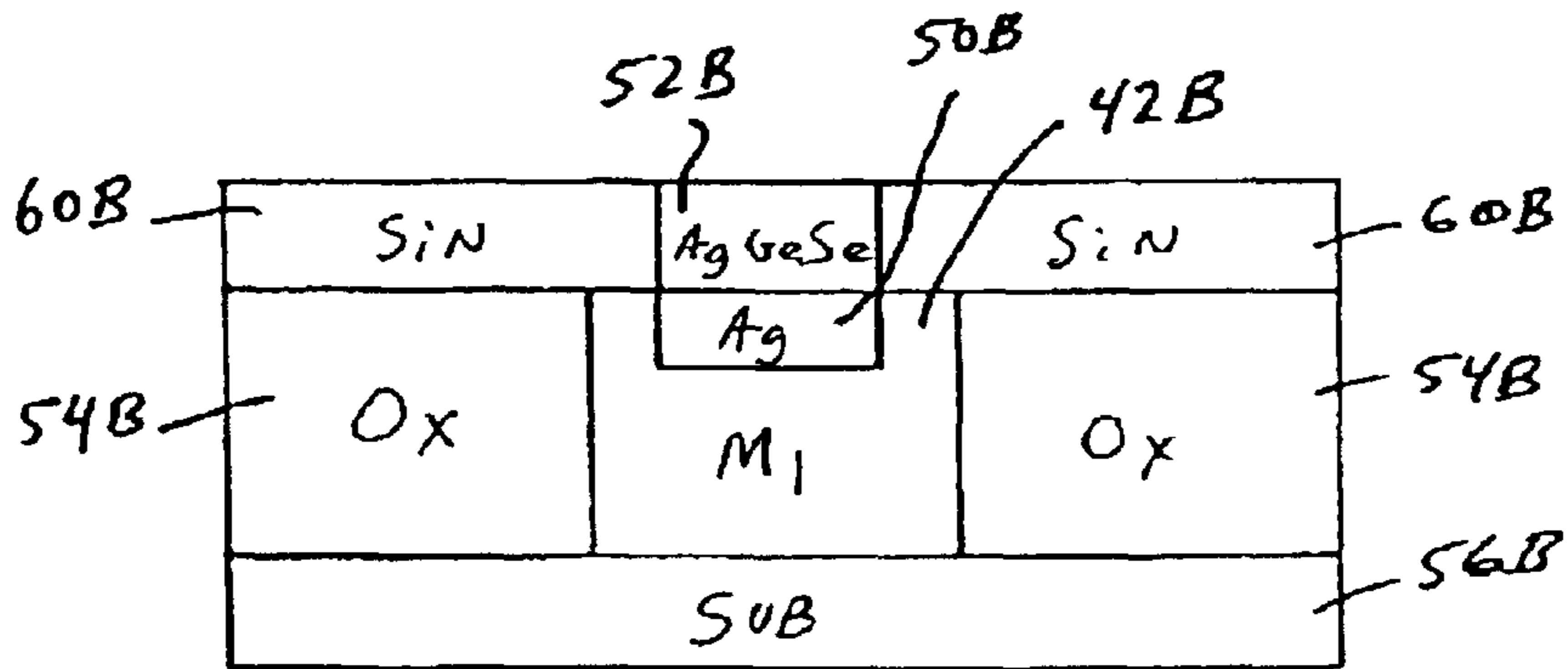


FIG. 14

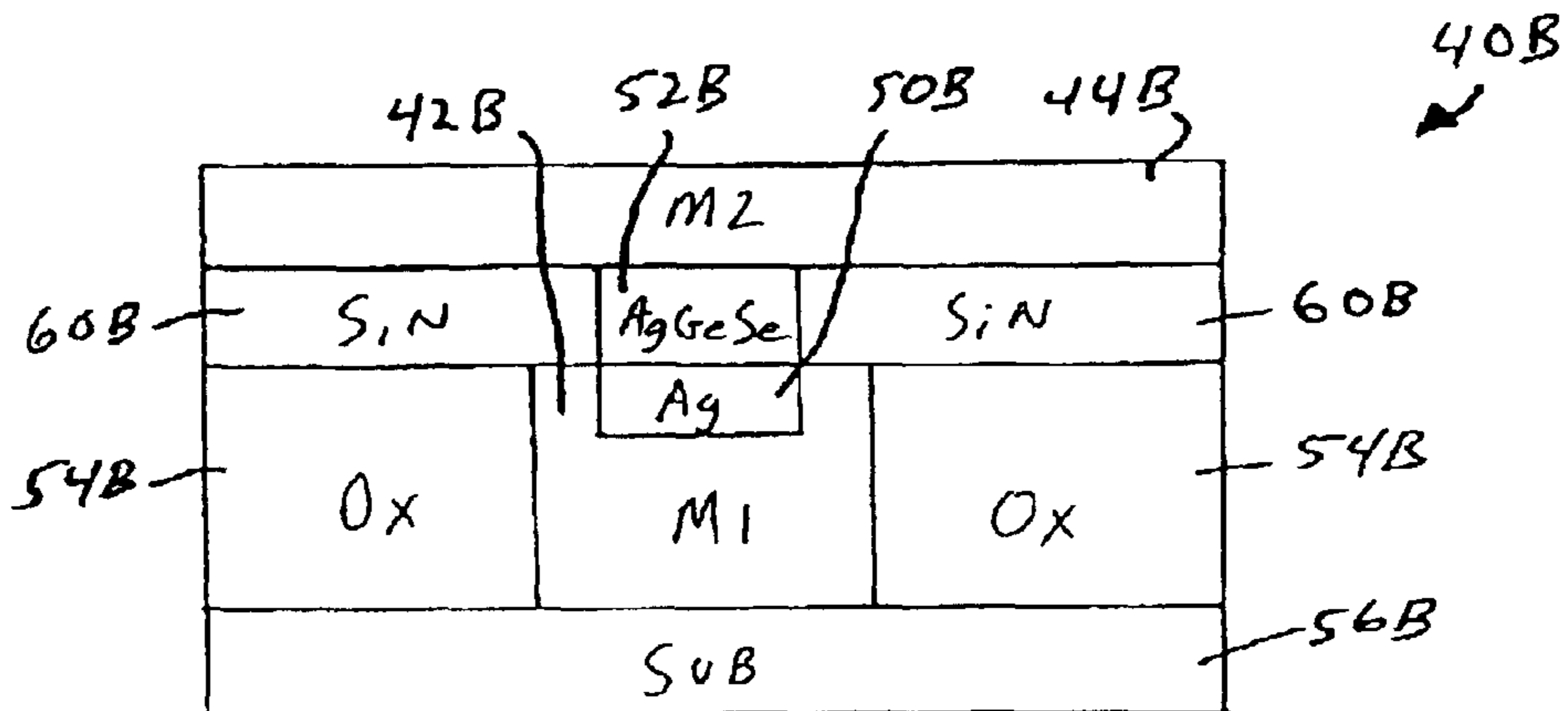


FIG. 15

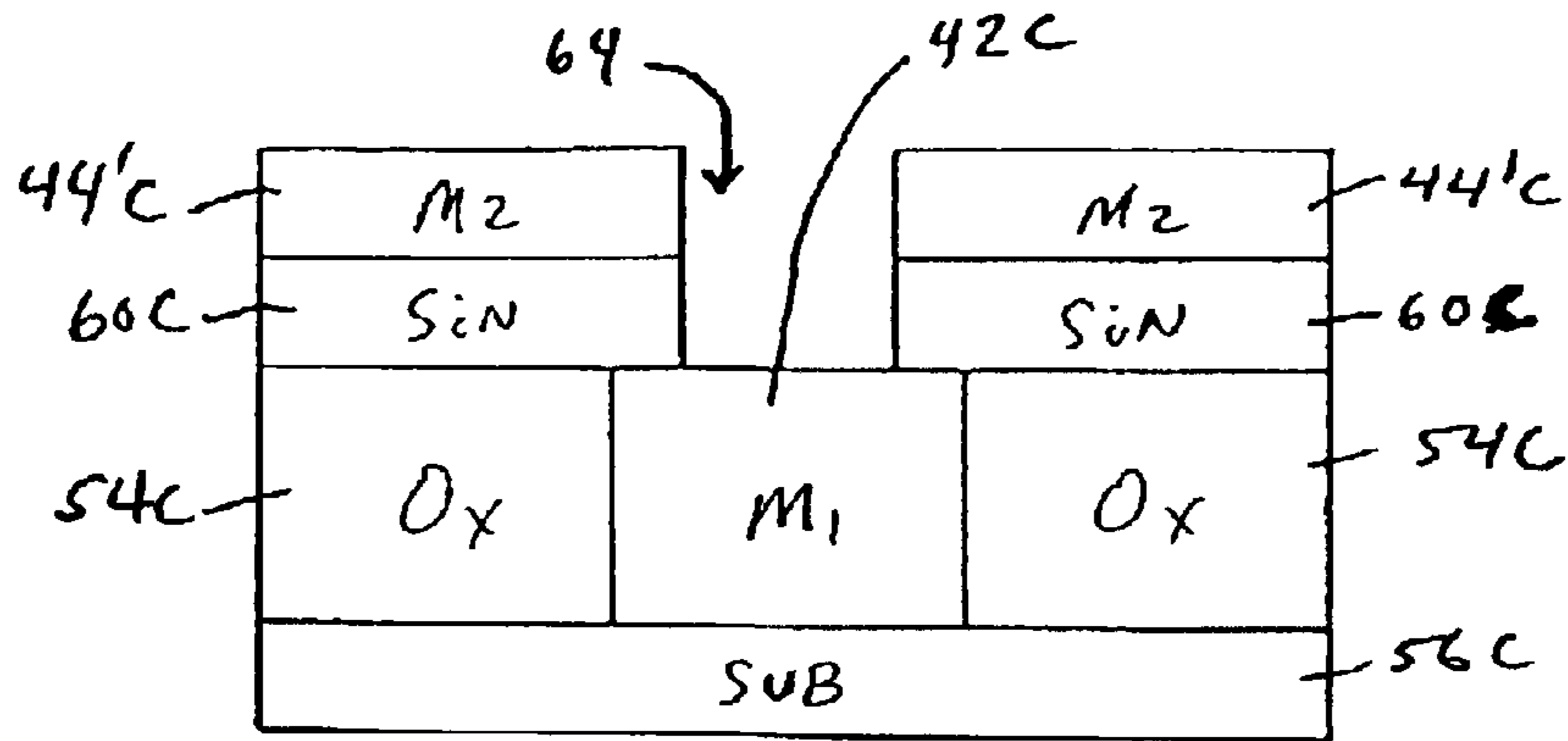


FIG. 16

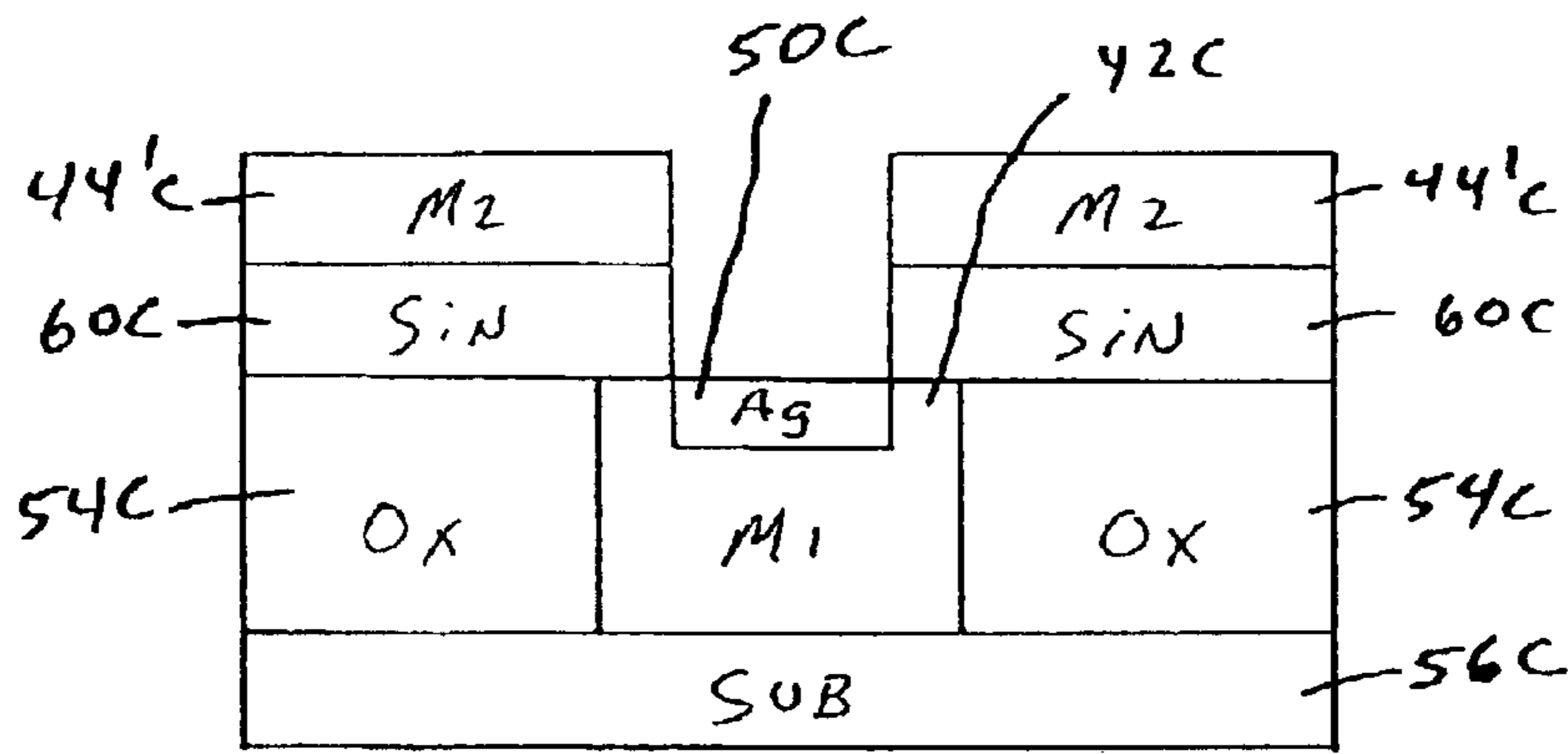


FIG. 17

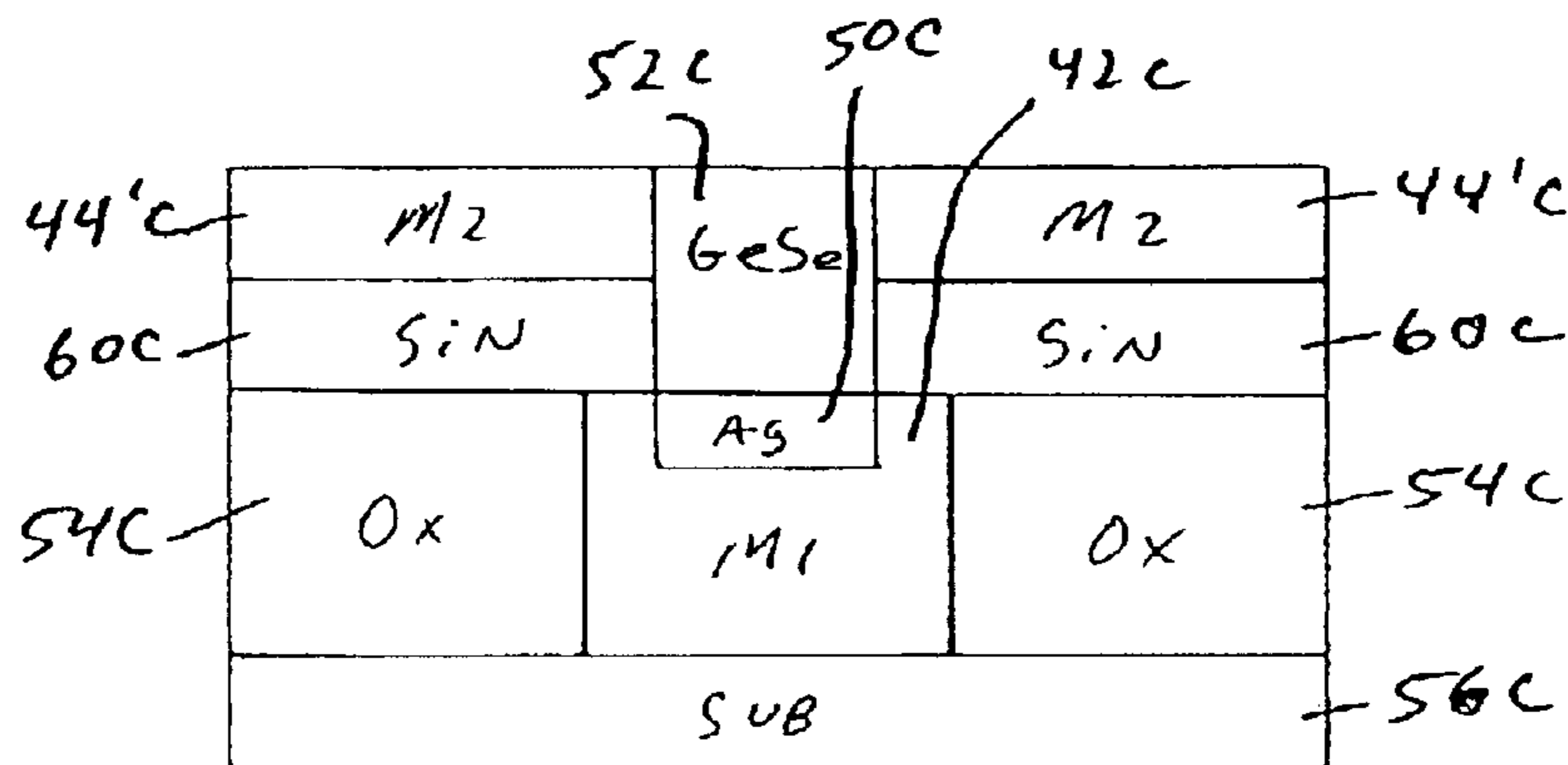


FIG. 18

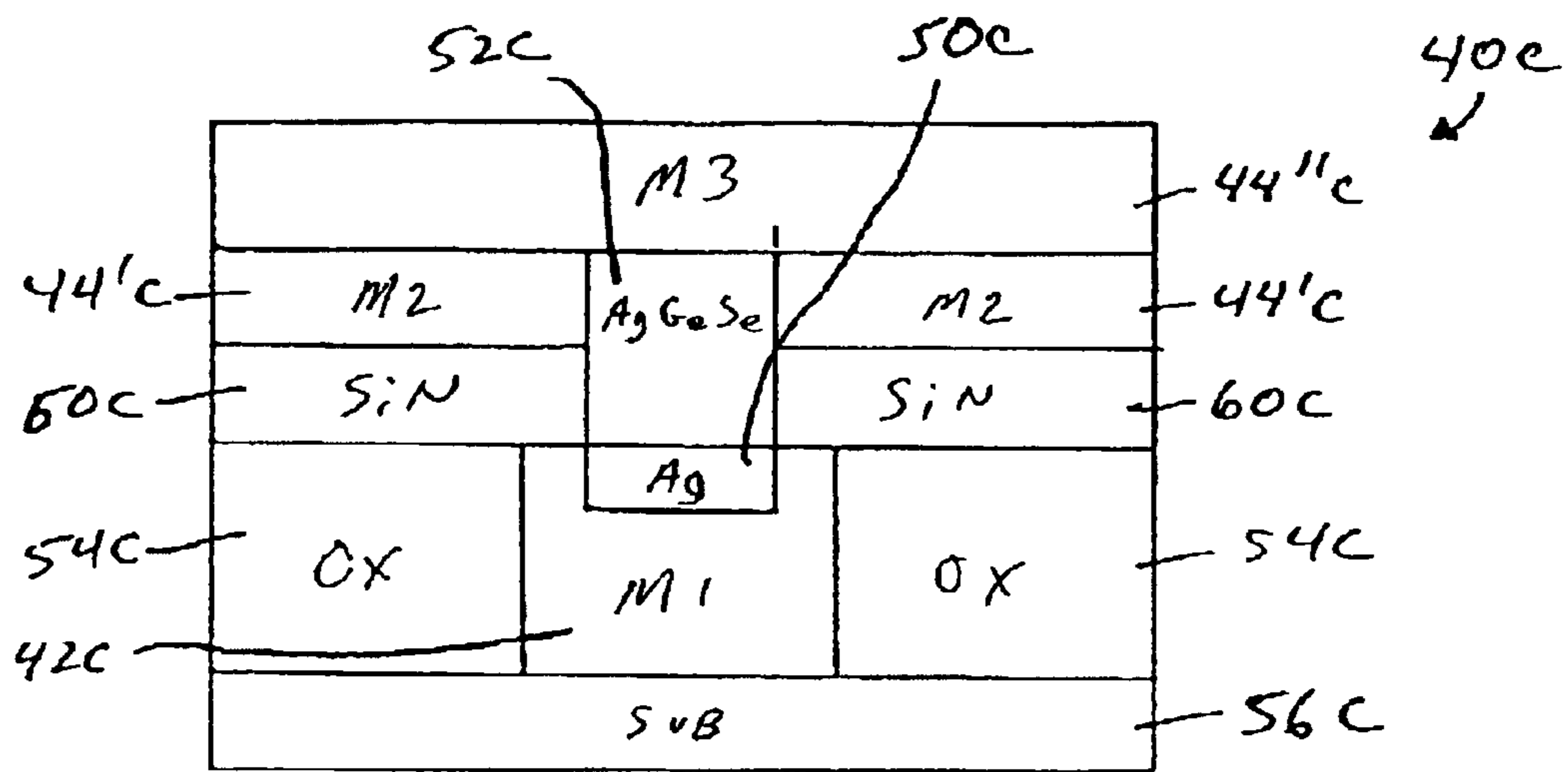


FIG. 19

## PCRAM MEMORY CELL AND METHOD OF MAKING SAME

This application is a continuation of Ser. No. 09/853,233 filed May 11, 2001.

### BACKGROUND OF THE INVENTION

#### 1. Field of the Invention

The invention relates generally to the field of semiconductor devices and fabrication and, more particularly, to memory elements and methods for making memory elements.

#### 2. Background of the Related Art

This section is intended to introduce the reader to various aspects of art which may be related to various aspects of the present invention that are described and/or claimed below. This discussion is believed to be helpful in providing the reader with background information to facilitate a better understanding of the various aspects of the present invention. Accordingly, it should be understood that these statements are to be read in this light, and not as admissions of prior art.

Microprocessor-controlled integrated circuits are used in a wide variety of applications. Such applications include personal computers, vehicle control systems, telephone networks, and a host of consumer products. As is well known, microprocessors are essentially generic devices that perform specific functions under the control of a software program. This program is stored in one or more memory devices that are coupled to the microprocessor. Not only does the microprocessor access memory devices to retrieve the program instructions, but it also stores and retrieves data created during execution of the program in one or more memory devices.

There are a variety of different memory devices available for use in microprocessor-based systems. The type of memory device chosen for a specific function within a microprocessor-based system depends largely upon what features of the memory are best suited to perform the particular function. For instance, volatile memories, such as dynamic random access memories (DRAMs), must be continually powered in order to retain their contents, but they tend to provide greater storage capability and programming options and cycles than non-volatile memories, such as read only memories (ROMs). While non-volatile memories that permit limited reprogramming exist, such as electrically erasable and programmable "ROMs," all true random access memories, i.e., those memories capable of  $10^{14}$  programming cycles are more, are volatile memories. Although one time programmable read only memories and moderately reprogrammable memories serve many useful applications, a true nonvolatile random access memory (NVRAM) would likely be needed to surpass volatile memories in usefulness.

Efforts have been underway to create a commercially viable memory device that is both random access and nonvolatile using structure changing memory elements, as opposed to the charge storage memory elements used in most commercial memory devices. The use of electrically writable and erasable phase change materials, i.e., materials which can be electrically switched between generally amorphous and generally crystalline states or between different resistive states while in crystalline form, in memory applications is known in the art and is disclosed, for example, in U.S. Pat. No. 5,296,716 to Ovshinsky et al. The Ovshinsky patent contains a discussion of the general theory of operation of chalcogenide materials, which are a particular type of structure changing material.

As disclosed in the Ovshinsky patent, such phase change materials can be electrically switched between a first structural state, in which the material is generally amorphous, and a second structural state, in which the material has a generally crystalline local order. The material may also be electrically switched between different detectable states of local order across the entire spectrum between the completely amorphous and the completely crystalline states. In other words, the switching of such materials is not required to take place in a binary fashion between completely amorphous and completely crystalline states. Rather, the material may be switched in incremental steps reflecting changes of local order to provide a "gray scale" represented by a multiplicity of conditions of local order spanning the spectrum from the completely amorphous state to the completely crystalline state.

These memory elements are monolithic, homogeneous, and formed of chalcogenide material typically selected from the group of Te, Se, Sb, Ni, and Ge. This chalcogenide material exhibits different electrical characteristics depending upon its state. For instance, in its amorphous state the material exhibits a higher resistivity than it does in its crystalline state. Such chalcogenide materials may be switched between numerous electrically detectable conditions of varying resistivity in nanosecond time periods with the input of picojoules of energy. The resulting memory element is truly non-volatile. It will maintain the integrity of the information stored by the memory cell without the need for periodic refresh signals, and the data integrity of the information stored by these memory cells is not lost when power is removed from the device. The memory material is also directly overwritable so that the memory cells need not be erased, i.e., set to a specified starting point, in order to change information stored within the memory cells. Finally, the large dynamic range offered by the memory material theoretically provides for the gray scale storage of multiple bits of binary information in a single cell by mimicking the binary encoded information in analog form and, thereby, storing multiple bits of binary encoded information as a single resistance value in a single cell.

Traditionally, the operation of chalcogenide memory cells requires that a region of the chalcogenide memory material, called the "active region," be subjected to a current pulse to change the crystalline state of the chalcogenide material within the active region. Typically, a current density of between about  $10^5$  and  $10^7$  amperes/cm<sup>2</sup> is needed. To obtain this current density in a commercially viable device having at least one million memory cells, for instance, one theory suggests that the active region of each memory cell should be made as small as possible to minimize the total current drawn by the memory device.

However, such traditional chalcogenide memory cells have evolved into what is referred to as a programmable metallization cell or a plated chalcogenide memory cell for use in a plated chalcogenide random access memory (PCRAM) device. Such a cell includes a chalcogenide material between opposing electrodes. A fast ion conductor material is incorporated into the chalcogenide material. The resistance of such material can be changed between highly resistive and highly conductive states.

To perform a write operation with the memory cell in its normal high resistive state, a voltage potential is applied to a certain one of the electrodes, with the other of the electrode being held at zero voltage or ground. The electrode having the voltage applied to it functions as an anode, while the electrode held at zero or ground functions as a cathode. The nature of the fast ion conductor material is such that it



undergoes a chemical and structural change at a certain applied voltage level. Specifically, at some suitable threshold voltage, the metal ions within the chalcogenide material begin to plate on the cathode and progress through the chalcogenide material toward the anode. The process continues until a conductive dendrite or filament extends between the electrodes, effectively interconnecting the top and bottom electrodes to create an electrical short circuit.

Once this occurs, dendrite growth stops, and the dendrite is retained when the voltage potentials are removed. This results in the resistance of the chalcogenide material between the electrodes dropping by a factor of about 1,000. The material can be returned to its highly resistive state by reversing the voltage potential between the anode and cathode to cause the dendrite to disappear. Again, the highly resistive state is maintained when the reverse voltage potential is removed. Accordingly, such a device can, for example, function as a reprogrammable memory cell of non-volatile random access memory circuit.

As mentioned above, the variable resistance material disposed between the electrodes typically is a chalcogenide material having metal ions diffused therein. A specific example is germanium selenide with silver ions. Typically, to provide the silver ions within the germanium selenide material, germanium selenide is deposited onto the first electrode using chemical vapor deposition. A thin layer of silver is then deposited on the glass, for example by physical vapor deposition or another technique. The layer of silver is then irradiated with ultraviolet radiation. The thin nature of the deposited silver allows the energy to pass through the silver to the silver/glass interface to cause the silver to diffuse into the chalcogenide material. The applied energy and overlying silver result in the silver migrating into the glass layer such that a homogenous distribution of silver throughout the layer is ultimately achieved.

Unfortunately, chalcogenide materials are relatively delicate. The nature of the deposition technique used to deposit the silver can damage the chalcogenide material, and, thus, adversely affect the resulting memory cell. Furthermore, it can be challenging to etch and polish chalcogenide materials. Accordingly, it would be desirable to develop memory cell fabrication methods that avoid steps that can damage such materials.

#### BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing and other advantages of the invention will become apparent upon reading the following detailed description and upon reference to the drawings in which:

FIG. 1 illustrates a block diagram of an exemplary processor-based device;

FIG. 2 illustrates an exemplary memory device;

FIG. 3 illustrates a more detailed view of the memory array of the memory device illustrated in FIG. 2;

FIGS. 4–10 illustrate cross-sectional views of a memory cell during different stages of fabrication;

FIGS. 11–15 illustrate cross-sectional views of an alternate embodiment of a memory cell during different stages of fabrication; and

FIGS. 16–19 illustrate cross-sectional views of another alternate embodiment of a memory cell during different stages of fabrication.

#### DETAILED DESCRIPTION OF SPECIFIC EMBODIMENTS

Specific embodiments of microprocessor-based systems, memories, memory elements, and methods of making such

memory elements are described below as they might be implemented for use in semiconductor memory circuits. In the interest of clarity, not all features of an actual implementation are described in this specification. It should be appreciated that in the development of any such actual implementation, as in any engineering project, numerous implementation-specific decisions must be made to achieve the developers' specific goals, such as compliance with system-related and business-related constraints, which may vary from one implementation to another. Moreover, it should be appreciated that such a development effort might be complex and time-consuming, but would nevertheless be a routine undertaking for those of ordinary skill having the benefit of this disclosure.

Turning now to the drawings, and referring initially to FIG. 1, a block diagram depicting an exemplary processor-based device, generally designated by the reference numeral 10, is illustrated. The device 10 may be any of a variety of different types, such as a computer, pager, cellular telephone, personal organizer, control circuit, etc. In a typical processor-based device, one or more processors 12, such as a microprocessor(s), control many of the functions of the device 10.

The device 10 typically includes a power supply 14. For instance, if the device 10 is portable, the power supply 14 would advantageously include permanent batteries, replaceable batteries, and/or rechargeable batteries. The power supply 14 may also include an A/C adapter, so that the device may be plugged into a wall outlet, for instance. In fact, the power supply 14 may also include a D/C adapter, so that the device 10 may be plugged into a vehicle's cigarette lighter, for instance.

Various other devices may be coupled to the processor(s) 12, depending upon the functions that the device 10 performs. For instance, a user interface 16 may be coupled to the processor(s) 12. The user interface 16 may include an input device, such as buttons, switches, a keyboard, a light pin, a mouse, and/or a voice recognition system, for instance. A display 18 may also be coupled to the processor(s) 12. The display 18 may include an LCD display, a CRT, LEDs, and/or an audio display. Furthermore, an RF subsystem/baseband processor 20 may also be coupled to the processor(s) 12. The RF subsystem/baseband processor 20 may include an antenna that is coupled to an RF receiver and to an RF transmitter (not shown). A communication port 22 may also be coupled to the processor(s) 12. The communication port 22 may be adapted to be coupled to a peripheral device 24, such as a modem, a printer, or a computer, for instance, or to a network, such as a local area network or the Internet.

Because the processor(s) 12 controls the functioning of the device 10 generally under the control of software programming, memory is coupled to the processor(s) 12 to store and facilitate execution of the software program. For instance, the processor(s) 12 may be coupled to volatile memory 26, which may include dynamic random access memory (DRAM), static random access memory (SRAM), Double Data Rate (DDR) memory, etc. The processor(s) 12 may also be coupled to non-volatile memory 28. The non-volatile memory 28 may include a read only memory (ROM), such as an EPROM or Flash Memory, to be used in conjunction with the volatile memory. The size of the ROM is typically selected to be just large enough to store any necessary operating system, application programs, and fixed data. The volatile memory, on the other hand, is typically quite large so that it can store dynamically loaded applications. Additionally, the non-volatile memory 28 may include

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a high capacity memory such as a disk drive, tape drive memory, CD ROM drive, DVD, read/write CD ROM drive, and/or a floppy disk drive.

An exemplary memory device is illustrated in FIG. 2 and generally designated by a reference numeral 30. The memory device 30 is an integrated circuit memory that is advantageously formed on a semiconductor substrate 32. The memory device 30 includes a memory matrix or array 34 that includes a plurality of memory cells for storing data, as described below. The memory matrix 34 is coupled to periphery circuitry 36 by the plurality of control lines 38. The periphery circuitry 36 may include circuitry for addressing the memory cells contained within the memory matrix 34, along with circuitry for storing data in and retrieving data from the memory cells. The periphery circuitry 36 may also include other circuitry used for controlling or otherwise insuring the proper functioning of the memory device 30.

A more detailed depiction of the memory matrix 34 is illustrated in FIG. 3. As can be seen, the memory matrix 34 includes a plurality of memory cells 40 that are arranged in generally perpendicular rows and columns. The memory cells 40 in each row are coupled together by a respective word line 42, and the memory cells 40 in each column are coupled together by a respective digit line 44. Specifically, each memory cell 40 includes a word line node 46 that is coupled to a respective word line 42, and each memory cell 40 includes a digit line node 48 that is coupled to a respective digit line 44. The conductive word lines 42 and digit lines 44 are collectively referred to as address lines. These address lines are electrically coupled to the periphery circuitry 36 so that each of the memory cells 40 can be accessed for the storage and retrieval of information.

Turning now to FIGS. 4–10, a first exemplary embodiment of a memory cell 40 will be described. FIG. 10 illustrates the finished memory cell 40A, and FIGS. 4–9 illustrate the memory cell 40A at various stages of fabrication. The suffix “A” is used in describing this first embodiment for clarity so that similar reference numerals may be used to describe subsequent embodiments. As illustrated in FIG. 10, the finished memory cell 40A includes a word line 42A, which is often referred to as a Metal 1 (M1) layer. The word line 42A has a layer of conductive material 50A, such as silver (Ag), disposed thereon. A layer of chalcogenide material 52A, such as germanium selenide (GeSe), having metal ions diffused therein is disposed over the conductive layer 50A. The metal ions diffused in the chalcogenide material 52A typically originate in the layer of conductive material 50A. The digit line 44A, often referred to as a Metal 2 (M2) layer, is disposed over the chalcogenide layer 52A. Each memory cell 40A is typically isolated from adjacent memory cells by oxide regions 54A, and each memory cell 40A is typically fabricated on a substrate 56A.

One method of fabricating the memory cell 40A is disclosed with reference to the various stages of fabrication illustrated in FIGS. 4–9. Referring first to FIG. 4, a substrate 56A is typically used as a base upon which the memory cells 40A of the memory array 44 are formed. In this discussion, the substrate 56A is generally used in a generic sense, because it is possible for the substrate 56A to take various forms depending upon the nature of the circuit design. For example, the substrate 56A may be a suitable semiconductor substrate, such as silicon or gallium arsenide, or a suitable dielectric substrate, such as PECVD silicon dioxide. Furthermore, the substrate 56A may include layers, devices, and/or structures upon which or around which the memory cells 40A may be fabricated.

A layer of dielectric material 54A, for example an oxide such as silicon dioxide, is formed over the substrate 56A, as

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illustrated in FIG. 5. The layer of dielectric material 54A may be formed by any suitable process, such as by chemical vapor deposition. A window 58A is formed in the layer of dielectric material 54A. The window may extend partially through the layer of dielectric material 54A, or completely through the layer of dielectric material 54A to the substrate 56A, as illustrated in FIG. 5. The window 58A may be formed by any suitable process, such as by the use of standard photolithographic techniques.

As illustrated in FIGS. 5 and 6, a layer of conductive material is deposited into the window 58A and planarized to form the word line 42A. Again, any suitable deposition technique, such as sputtering, and any suitable planarization technique, such as chemical mechanical planarization (CMP), may be used. The conductive material used to form the word line 42A is typically a metal, such as copper, tungsten, nickel, or aluminum. Although the word line 42A is illustrated as being formed in a dielectric material 54A in this embodiment, it should be appreciated that the word line 42A may be formed in other manners as well. For example, the word line 42A may be buried in the substrate 56A.

A fast ion conductive material is then disposed on the word line 42A. The fast ion conductive material is selected to cooperate with a subsequently applied layer of chalcogenide material to form the memory element of the memory cell 40A. In this embodiment, the word line 42A is plated with the conductive material 50A using an immersion plating process. In general, immersion plating replaces a less noble metal with a more noble metal. It is an ion exchange process that requires neither external electricity nor a catalyst. Immersion plating can be used in a self-limiting process, and it usually plates thinner films than other plating methods. Immersion plating depends on the base metal, i.e., the less noble metal. Many factors can influence immersion plating, such as the type of ligand used to take up the base metal and to keep the base metal in solution.

In this exemplary embodiment, the base metal of the word line 42A is selected to be copper, and the more noble metal of the conductive layer 50A is selected to be silver. Of course, it should be recognized that other base metals, such as nickel, aluminum, or tungsten, for example, may be used in place of copper, and that alloys of such metals may be used as well. In addition, various “more noble” metals, such as gold, may be used in place of silver. However, for the purposes of this exemplary embodiment utilizing copper and silver, a silver immersion solution called “argentomerse” available from Technic, Inc. may be used. This silver immersion solution utilizes a cyanide salt chemistry, which essentially represents a general purpose immersion plating solution. A silver immersion solution such as argentomerse should suffice for plating silver on base metals such as nickel or copper. However, for immersion plating of silver on tungsten, it may be desirable to utilize another silver immersion solution in order to optimize the chemistry. The structure illustrated in FIG. 6 is immersed in the silver immersion solution for a sufficient amount of time to form the layer of conductive material 50A. For example, the structure may be immersed in the solution for 15 to 30 minutes to form the conductive layer 50A having a thickness of 500A to 2000A.

After the conductive layer 50A has been formed on the word line 42A, a layer of chalcogenide material 52A, such as germanium selenide, may be formed over the conductive layer 50A, as illustrated in FIG. 8. The layer of chalcogenide material 52A may be formed by any suitable process, such as chemical vapor deposition. The layer of chalcogenide material 52A may have a thickness in the range of 200A to 800A, for example.

Once the layer of chalcogenide material **52A** is formed over the layer of conductive material **50A**, the structure illustrated in FIG. **8** is processed in a manner that causes at least a portion of the material in the conductive layer **50A** to migrate into the layer of chalcogenide material **52A**. In this embodiment, the structure illustrated in FIG. **8** is subjected to ultraviolet radiation and heat to cause silver atoms in the layer of conductive material **50A** to migrate into the layer of chalcogenide material **52A**. For example, the structure in FIG. **8** may be submitted to ultraviolet radiation in the range of 160 nm to 904 nm, e.g., 405 nm, at an intensity of 10 microjoules to 10 millijoules for a period of 5 to 30 minutes, and heat at a temperature of 50 to 85 degrees Celsius for a period of 5 to 20 minutes. Typically, the heat cycle is performed first, followed by the UV cycle.

After this conversion process, the layer of chalcogenide material **52A** has metal ions in it, as illustrated in FIG. **9**. Then, the Metal 2 (M2) layer, which forms the digit line **44A**, may be disposed over the layer of chalcogenide material **52A**, as illustrated in FIG. **10**, to complete the memory cell **40A**.

It should be appreciated from the discussion of the structure and method of fabrication of the memory cell **40A** that it represents an inverted PCRAM memory cell. As discussed previously, a typical PCRAM memory cell is fabricated by forming a layer of chalcogenide material on the Metal 1 layer, thus requiring the conductive layer, such as silver, to be disposed on the chalcogenide layer. However, because chalcogenide is a very delicate material as discussed previously, known methods of depositing silver on chalcogenide are difficult to control in a reliable and repeatable fashion. However, by inverting the traditional PCRAM memory cell so that the conductive layer, such as silver, is disposed on the Metal 1 layer, the delicate nature of the subsequently deposited chalcogenide material does not pose a problem.

FIGS. **11–15** illustrate a second embodiment of the memory cell **40**. FIG. **15** illustrates the finished memory cell **40B**, and FIGS. **11–14** illustrate the memory cell **40B** at various stages of fabrication. The suffix “B” is used in describing this second embodiment for clarity so that similar reference numerals may be used. As illustrated in FIG. **15**, the finished memory cell **40B** includes a word line **42B**, which is again referred to as a Metal 1 (M1) layer. The word line **42B** has a layer of conductive material **50B**, such as silver (Ag), disposed thereon. A layer of chalcogenide material **52B**, such as germanium selenide (GeSe), having metal ions diffused therein is disposed over the conductive layer **50B**. Unlike the first embodiment, the layer of conductive material **50B** and the layer of chalcogenide material **52B** are disposed in a window created in a layer of dielectric material **60B**. The digit line **44B**, again referred to as a Metal 2 (M2) layer, is disposed over the chalcogenide layer **52B**. Each memory cell **40B** is typically isolated from adjacent memory cells by oxide regions **54B**, and each memory cell **40B** is typically fabricated on a substrate **56B**.

One method of fabricating the memory cell **40B** is disclosed with reference to, the various stages of fabrication illustrated in FIGS. **11–14**. However, before discussing FIGS. **11–14**, it should be understood that the memory cell **40B** first undergoes the stages of fabrication illustrated in FIGS. **4–6**. Then, as illustrated in FIG. **11**, a layer of dielectric material **60B** is deposited over the structure, and a window **62** is formed in the layer of dielectric material **60B** to expose at least a portion of the underlying word line **42B**. The layer of dielectric material **60B** may be deposited in any suitable manner, such as by chemical vapor deposition, and

it may include any suitable dielectric, such as silicon nitride. The thickness of the layer of dielectric material **60B** may be in the range of 200A to 1000A, for example.

A fast ion conductive material is then disposed on the portion of the word line **42B** exposed by the window **62**. The selection of the fast ion conductive material and the manner in which it may be applied does not differ from the previous embodiment. Accordingly, for the sake of clarity, in this exemplary embodiment, the base metal of the word line **42B** is selected to be copper, and the more noble metal of the conductive layer **50B** is selected to be silver. The structure illustrated in FIG. **11** is immersed in the silver immersion solution for a sufficient amount of time to form the layer of conductive material **50B**, as illustrated in FIG. **12**.

After the conductive layer **50B** has been formed on the word line **42B**, a layer of chalcogenide material **52B**, such as germanium selenide, may be deposited in the window **62** over the conductive layer **50B**, as illustrated in FIG. **13**. The layer of chalcogenide material **52B** may be formed by any suitable process, such as chemical vapor deposition. The deposited layer of chalcogenide material **52B** is then planarized, by chemical mechanical planarization for example, so that the layer of chalcogenide material **52B** remains only within the window **62**. Thus, the thickness of the layer of chalcogenide material **52B** is approximately the same as the thickness of the layer of dielectric material **60B**.

Once the layer of chalcogenide material **52B** is formed in the window **62**, the structure illustrated in FIG. **13** is processed in a manner that causes at least a portion of the material in the conductive layer **50B** to migrate into the layer of chalcogenide material **52B**. As in the previous embodiment, the structure illustrated in FIG. **13** is subjected to ultraviolet radiation and heat to cause silver atoms in the layer of conductive material **50B** to migrate into the layer of chalcogenide material **52B**.

After this conversion process, the layer of chalcogenide material **52B** has metal ions in it, as illustrated in FIG. **14**. Then, the Metal 2 (M2) layer, which forms the digit line **44B**, may be disposed over the layer of dielectric material **60B** and over the layer of chalcogenide material **52B**, as illustrated in FIG. **15**, to complete the memory cell **40B**.

FIGS. **16–19** illustrate a third embodiment of the memory cell **40**. FIG. **19** illustrates the finished memory cell **40C**, and FIGS. **16–18** illustrate the memory cell **40C** at various stages of fabrication. The suffix “C” is used in describing this third embodiment for clarity so that similar reference numerals may be used. As illustrated in FIG. **19**, the finished memory cell **40C** includes a word line **42C**, which is again referred to as a Metal 1 (M1) layer. The word line **42C** has a layer of conductive material **50C**, such as silver (Ag), disposed thereon. A layer of chalcogenide material **52C**, such as germanium selenide (GeSe), having metal ions diffused therein is disposed over the conductive layer **50C**. Unlike the previous embodiments, the layer of conductive material **50C** and the layer of chalcogenide material **52C** are disposed in a window created in a layer of dielectric material **60C** and in a layer of conductive material **44'C**. The layer of conductive material **44'C** forms a portion of the digit line and is again referred to as a Metal 2 (M2) layer. The other portion of the digit line is formed by a layer of conductive material **44''C**, which is disposed over the chalcogenide layer **52C** and over the Metal 2 layer. The layer of conductive material **44''C** is referred to as the Metal 3 (M3) layer. Each memory cell **40C** is typically isolated from adjacent memory cells by oxide regions **54C**, and each memory cell **40C** is typically fabricated on a substrate **56C**.

One method of fabricating the memory cell 40C is disclosed with reference to the various stages of fabrication illustrated in FIGS. 16–18. However, before discussing FIGS. 16–18, it should be understood that the memory cell 40C first undergoes the stages of fabrication illustrated in FIGS. 4–6. Then, as illustrated in FIG. 16, a layer of dielectric material 60C is deposited over the structure, and a layer of conductive material 44'C. (the Metal 2 layer) is deposited over the layer of dielectric material 60C. The layer of dielectric material 60C may be deposited in any suitable manner, such as by chemical vapor deposition, and it may include any suitable dielectric, such as silicon nitride. The layer of conductive material 44'C. may be deposited in any suitable manner, such as by sputtering, and it may include any suitable conductive material, such as platinum, aluminum, or tungsten. The thickness of the layer of dielectric material 60C may be in the range of 200Å to 1000Å, for example, and the thickness of the layer of conductive material 44'C. may be in the range of 500Å to 2000Å, for example.

A window 64 is formed in the layer of dielectric material 60C and in the layer of conductive material 44'C. to expose at least a portion of the underlying word line 42C. The window 64 may be formed in any suitable manner, such as by the use of standard photolithographic techniques.

A fast ion conductive material is then disposed on the portion of the word line 42C exposed by the window 64. The selection of the fast ion conductive material and the manner in which it may be applied does not differ from the previous embodiments. Accordingly, for the sake of clarity, in this exemplary embodiment, the base metal of the word line 42C is selected to be copper, and the more noble metal of the conductive layer 50C is selected to be silver. The structure illustrated in FIG. 16 is immersed in the silver immersion solution for a sufficient amount of time to form the layer of conductive material 50C, as illustrated in FIG. 17.

After the conductive layer 50C has been formed on the word line 42C, a layer of chalcogenide material 52C, such as germanium selenide, may be deposited in the window 64 over the conductive layer 50C, as illustrated in FIG. 18. The layer of chalcogenide material 52C may be formed by any suitable process, such as chemical vapor deposition. The deposited layer of chalcogenide material 52C is then planarized, by chemical mechanical planarization for example, so that the layer of chalcogenide material 52C remains only within the window 64. Thus, the thickness of the layer of chalcogenide material 52C is approximately the same as the thickness of the layers of dielectric material 60C and conductive material 44'C.

Once the layer of chalcogenide material 52C is formed in the window 64, the structure illustrated in FIG. 18 is processed in a manner that causes at least a portion of the material in the conductive layer 50C to migrate into the layer of chalcogenide material 52C. As in the previous embodiments, the structure illustrated in FIG. 18 is subjected to ultraviolet radiation and heat to cause silver atoms in the layer of conductive material 50C to migrate into the layer of chalcogenide material 52C.

After this conversion process, the layer of chalcogenide material 52C has metal ions in it, as illustrated in FIG. 19. Then, a layer of conductive material 44''C (the Metal 3 layer), which forms the remainder of the digit line, may be disposed over the layer of conductive material 44'C. and over the layer of chalcogenide material 52C to complete the memory cell 40C.

As previously mention, chalcogenide material is somewhat susceptible to damage from planarization techniques,

such as chemical mechanical planarization. However, it should be noted that the memory cell 40C is relatively immune to any “over planarization” of the chalcogenide material 52C within the window 64. Although the planarization step can remove some of the relatively delicate chalcogenide material 52C from the top of the window 64, the electrical path from the digit line 44C through the chalcogenide material 52C typically does not extend directly from the layer of conductive material 44''C. Rather, the shortest path typically extends from the edge of the layer of conductive material 44'C. Thus, for over planarization to affect the memory cell 40C adversely, chalcogenide material 52C below the level of the dielectric layer 60C would have to be removed. Since over planarization to such an extent is unlikely, the memory cell 40C typically provides for relatively repeatable and consistent memory operation.

While the invention may be susceptible to various modifications and alternative forms, specific embodiments have been shown by way of example in the drawings and have been described in detail herein. However, it should be understood that the invention is not intended to be limited to the particular forms disclosed. Rather, the invention is to cover all modifications, equivalents, and alternatives falling within the spirit and scope of the invention as defined by the following appended claims.

What is claimed is:

1. A method of fabricating a memory cell, the method comprising the acts of:

- a. disposing a first line over a substrate, the first line being formed of a first metal;
- b. plating the first line with a second metal by immersion in a solution containing the second metal;
- c. disposing a layer of chalcogenide material over the second metal;
- d. transferring ions of the second metal into the chalcogenide material; and
- e. disposing a second line over the layer of chalcogenide material, the second line being formed of a third metal.

2. The method, as set forth in claim 1, wherein act (a) comprises the act of: disposing at least one of copper, nickel, and tungsten over the substrate.

3. The method, as set forth in claim 1, wherein the second metal comprises silver.

4. The method, as set forth in claim 1, wherein act (c) comprises the act of: disposing germanium selenide over the second metal.

5. The method, as set forth in claim 1, wherein act (d) comprises the act of: heating the second metal and the chalcogenide material.

6. The method, as set forth in claim 1, wherein act (d) comprises the act of: irradiating the second metal and the chalcogenide material with ultraviolet radiation.

7. The method, as set forth in claims 1, wherein acts (a) through (e) are performed in the order recited.

8. The method, as set forth in claim 7, further comprising the act of: prior to transferring ions of the second metal into the chalcogenide material, planarizing the chalcogenide material disposed over the second metal.

9. A method of fabricating a memory cell, the method comprising the acts of:

- a. disposing a layer of dielectric material over a substrate;
- b. forming a window in the layer of dielectric material;
- c. disposing a first metal in the window;
- d. plating the first metal with a second metal by immersion in a solution containing the second metal;

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- e. disposing a layer of chalcogenide material over the second metal;
- f. transferring ions of the second metal into the chalcogenide material; and
- g. disposing a third metal over the layer of chalcogenide material.

10. The method, as set forth in claim 9, wherein act (a) comprises the act of: disposing a layer of oxide over the substrate.

11. The method, as set forth in claim 9, wherein act (c) comprises the act of: disposing at least one of copper, nickel, and tungsten in the window.

12. The method, as set forth in claim 9, wherein the second metal comprises silver.

13. The method, as set forth in claim 9, wherein act (e) comprises the act of: disposing germanium selenide over the second metal.

14. The method, as set forth in claim 9, wherein act (f) comprises the act of: heating the second metal and the chalcogenide material.

15. The method, as set forth in claim 9, wherein act (f) comprises the act of: irradiating the second metal and the chalcogenide material with ultraviolet radiation.

16. The method, as set forth in claim 9, wherein acts (a) through (g) are performed in the order recited.

17. A method of fabricating a memory cell, the method comprising the acts of:

- a. disposing a first layer of dielectric material on a substrate;
- b. forming a first window in the first layer of dielectric material;
- c. disposing a first metal in the first window;
- d. disposing a second layer of dielectric material over the first metal and the first layer of dielectric material;
- e. forming a second window in the second layer of dielectric material to expose at least a portion of the first metal in the first window;
- f. plating the first metal exposed by the second window with a second metal by immersion in a solution containing the second metal;
- g. disposing a layer of chalcogenide material over the second metal;
- h. transferring ions of the second metal into the chalcogenide material; and
- i. disposing a third metal over the layer of chalcogenide material.

18. The method, as set forth in claim 17, wherein act (a) comprises the act of: disposing a layer of oxide over the substrate.

19. The method, as set forth in claim 17, wherein act (c) comprises the act of: disposing at least one of copper, nickel, and tungsten in the window.

20. The method, as set forth in claim 17, wherein act (d) comprises the act of: disposing a layer of silicon nitride over the first metal and the first layer of dielectric material.

21. The method, as set forth in claim 17, wherein the second metal comprises silver.

22. The method, as set forth in claim 17, wherein act (g) comprises the act of: disposing germanium selenide over the second metal.

23. The method, as set forth in claim 17, wherein act (h) comprises the act of: heating the second metal and the chalcogenide material.

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24. The method, as set forth in claim 17, wherein act (h) comprises the act of: irradiating the second metal and the chalcogenide material with ultraviolet radiation.

25. The method, as set forth in claim 17, wherein acts (a) through (i) are performed in the order recited.

26. The method, as set forth in claim 25, further comprising the act of: prior to transferring ions of the second metal into the chalcogenide material, planarizing the chalcogenide material disposed over the second metal.

27. A method of fabricating a memory cell, the method comprising the acts of:

- a. disposing a first layer of dielectric material on a substrate;
- b. forming a first window in the first layer of dielectric material;
- c. disposing a first metal in the first window;
- d. disposing a second layer of dielectric material over the first metal and the first layer of dielectric material;
- e. disposing a layer of a second metal over the second layer of dielectric material
- f. forming a second window in the second layer of dielectric material and in the layer of the second metal to expose at least a portion of the first metal in the first window;
- g. plating the first metal exposed by the second window with a third metal by immersion in a solution containing the third metal;
- h. disposing a layer of chalcogenide material over the third metal;
- i. transferring ions of the third metal into the chalcogenide material; and
- j. disposing a fourth metal over the layer of chalcogenide material.

28. The method, as set forth in claim 27, wherein act (a) comprises the act of: disposing a layer of oxide over the substrate.

29. The method, as set forth in claim 27, wherein act (c) comprises the act of: disposing at least one of copper, nickel, and tungsten in the window.

30. The method, as set forth in claim 27, wherein act (d) comprises the act of: disposing a layer of silicon nitride over the first metal and the first layer of dielectric material.

31. The method, as set forth in claim 27, wherein the third metal comprises silver.

32. The method, as set forth in claim 27, wherein act (h) comprises the act of: disposing germanium selenide over the third metal.

33. The method, as set forth in claim 27, wherein act (i) comprises the act of: heating the third metal and the chalcogenide material.

34. The method, as set forth in claim 27, wherein act (i) comprises the act of: irradiating the third metal and the chalcogenide material with ultraviolet radiation.

35. The method, as set forth in claim 27, wherein acts (a) through (j) are performed in the order recited.

36. The method, as set forth in claim 35, further comprising the act of: prior to transferring ions of the third metal into the chalcogenide material, planarizing the chalcogenide material disposed over the third metal.

UNITED STATES PATENT AND TRADEMARK OFFICE  
**CERTIFICATE OF CORRECTION**

PATENT NO. : 7,071,021 B2  
APPLICATION NO. : 10/205387  
DATED : July 4, 2006  
INVENTOR(S) : Steven T. Harshfield et al.

Page 1 of 3

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

On title page in Item (63) Related U.S. Application Data, and also in the sentence following the title of the patent just before the Specification, the word "continuation" should read --divisional--.

In the Item [56] Other Publications portion of the References Cited section, the following publication should be added:

--HELBERT et al., *Intralevel hybrid resist process with submicron capability*, SPIE Vol. 333 SUBMICRON LITHOGRAPHY, pp. 24-29 (1982).--

Also, in the Item [56] Other Publications portion, the following errors are corrected:

"El Bouchairi, B.; Bernede, J.C.; Burgaud, P., Propeties of  $Ag_{2-x}Se_{1+x/n}$ -Si diodes, Thin Solid Films 110 (1983) 107-113."

**Should read**

--El Bouchairi, B.; Bernede, J.C.; Burgaud, P., Properties of  $Ag_{2-x}Se_{1+x/n}$ -Si diodes, Thin Solid Films 110 (1983) 107-113.--;

"Hajto, J.; McAuley, B.; Snell, A.J.; Owen, A.E., Theory of room temperature quantized resistance effects in metal-a-Si:H-metal thin film structuress, J. Non-Cryst. Solids 198-200 (1996) 825-828."

**Should read**

--Hajto, J.; McAuley, B.; Snell, A.J.; Owen, A.E., Theory of room temperature quantized resistance effects in metal-a-Si:H-metal thin film structures, J. Non-Cryst Solids 198-200 (1996) 825-828.--;

"Hegab, N.A.; Fadel, M.; Sedeek, K., Memory switching pehnomena in thin films of chalcogenide semiconductors, Vacuum 45 (1994) 459-462."

**Should read**

--Hegab, N.A.; Fadel, M.; Sedeek, K., Memory switching phenomena in thin films of chalcogenide semiconductors, Vacuum 45 (1994) 459-462.--.

UNITED STATES PATENT AND TRADEMARK OFFICE  
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PATENT NO. : 7,071,021 B2  
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DATED : July 4, 2006  
INVENTOR(S) : Steven T. Harshfield et al.

Page 2 of 3

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

“Kotkata, M.F.; Afif, M.A.; Labib, H.H.; Hegab, N.A.; Abdel-Aziz, M.M.,  
Memory switching in amorphous GeSeTI chalcogenide semiconductor films, Thin Solid  
Films 240 (1994) 143-146.”

**Should read**

--Kotkata, M.F.; Afifi, M.A.; Labib, H.H.; Hegab, N.A.; Abdel-Aziz, M.M.,  
Memory switching in amorphous GeSeTI chalcogenide semiconductor films, Thin Solid  
Films 240 (1994) 143-146.--;

“McHardy et al., *The dissolution of metals in amorphous chalcogenides and the  
effects o electron and ultraviolet radiation*, 20 J. Phys. C.: Solid State Phys., pp. 4055-  
4075 (1987)f.”

**Should read**

--McHardy et al., *The dissolution of metals in amorphous chalcogenides and the  
effects of electron and ultraviolet radiation*, 20 J. Phys. C.: Solid State Phys., pp. 4055-  
4075 (1987).--; and

“Tranchant, S.; Peytavin, S.; Ribes, M.; Flank, A.M.; Dexpert, H.; Lagarde,  
J.P., Silver chalcogenide glasses Ag-Ge-Se: Ionic conduction and exafs structural  
investigation, Transport-structure relations in fast ion and mixed conductors  
Proceedings of the 6th Riso International symposium, Sep. 9-13, 1985.”

**Should read**

--Tranchant, S.; Peytavin, S.; Ribes, M.; Flank, A.M.; Dexpert, H.; Lagarde,  
J.P., Silver chalcogenide glasses Ag-Ge-Se: Ionic conduction and EXAFS structural  
investigation, Transport-structure relations in fast ion and mixed conductors, Proc. of  
the 6th RISO Int'l Symp., Sep. 9-13, 1985.--

In the Specification, the following error is corrected:

Column 1, line 49, “are more” should read --or more--.

UNITED STATES PATENT AND TRADEMARK OFFICE  
**CERTIFICATE OF CORRECTION**

PATENT NO. : 7,071,021 B2  
APPLICATION NO. : 10/205387  
DATED : July 4, 2006  
INVENTOR(S) : Steven T. Harshfield et al.

Page 3 of 3

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

In the Claims, No. 83 on the application should be added as follows:

Col. 12, lines 65-66

--37. The method, as set forth in claim 16, further comprising the act of:

prior to transferring ions of the second metal into the chalcogenide material,  
planarizing the chalcogenide material disposed over the second metal.--

Signed and Sealed this

Thirteenth Day of November, 2007

A handwritten signature in black ink on a light gray dotted background. The signature reads "Jon W. Dudas" in a cursive style.

JON W. DUDAS

*Director of the United States Patent and Trademark Office*